AD-A034 491 TETRA TECH INC PASADENA CALIF F/G 13/10

VULNERABILITY OF SURFACE EFFECT VEHICLES TO EXPLOSION-GENERATED--ETC(U)

NOV 76 R B WADE, S WANG, T W WIER N00014-76-C-0261

UNCLASSIFIED TETRAT-TC-645 NL

1 OF 2

AD A034491

(12)

INTERIM REPORT

VULNERABILITY OF SURFACE EFFECT VEHICLES TO EXPLOSION GENERATED WATER WAVES

Prepared for:

Office of Naval Research
Arlington, Virginia

Prepared by:

R. B. Wade
S. Wang
T. W. Wier

Contract No.: N-00014-76-C-0261
Tetra Tech Contract No. TC-645

November 1976

TETRA TECH

INTERIM REPORT

VULNERABILITY OF SURFACE EFFECT VEHICLES TO EXPLOSION GENERATED WATER WAVES

Prepared for:

Office of Naval Research
Arlington, Virginia

Prepared by:

R. B. Wade
S. Wang
T. W. Wier

Contract No.: N-00014-76-C-0261
Tetra Tech Contract No. TC-645

November 1976

Tetra Tech Incorporated
630 North Rosemead Boulevard
Pasadena, California, 91107

TABLE OF CONTENTS

1. INTRODUCTION

Currently, there is a concerted effort being made by the Navy and other Governmental agencies in exploring the feasibility of using alternate concepts to present day naval ship design for the Navy of the future. These investigations have led to the consideration of Air Cushion Vehicles (ACV) and Surface Effects Ships (SES) as viable candidates. These vehicles offer the potential for much greater versatility and higher operational speeds than hithertofore possible with conventional ship design. The ACV with its totally flexible skirt system presents an amphibious capability most attractive for coastal and near-shore operations, assault landing operations, and for arctic environmental use. The SES, on the otherhand, while not of an amphibious nature, provides an ocean going vehicle capable of very high speed performance in reasonable sea states and weather conditions.

Interest in these concepts has led the Navy into a development program in which two air cushion assault vehicles are presently being constructed for evaluation purposes. Additionally, two 100-ton surface effect ships have been built and tested, under Navy contract, with sufficiently encouraging results that the Navy is currently conducting a detail design of a 3000-ton class SES. It is apparent from this activity that more than just casual interest is being given to these vehicles and indeed, dependent on the results of the above programs, they may prove to be the forerunners of a completely new class of fighting ship for the Navy of tomorrow.

The advent of the Surface Effect Vehicle as a serious contender for Naval applications has led to the need for an evaluation of the vulnerability of this type of craft under typical tactical situations. As presently envisaged the role these vehicles are to play in naval operations is one of antisubmarine warfare (ASW),

escort duties and near or offshore patrol and rescue, which operations require a dash or high speed capability coupled with maneuverability, a feature characteristic of air cushion vehicles (ACV) and surface effect ships (SES) alike.

Due to this mounting interest it is appropriate, at this time, to obtain an assessment of the vulnerability of such craft to possible threats. In identifying possible threat areas one outstanding possibility is that due to explosion generated waves. Past experience in this field, Reference 1 and 2, has shown the great damage potential such a phenomenon can have on submarines and conventional ships. The effects on ACV's and SES are expected to be of greater significance since the unique features of these vehicles make them particularly susceptible to sudden and anomalous changes in sea surface topography, such as are known to be produced by nuclear detonations.

Past studies have been primarily concerned with the behavior of ships and submarines within the transient surf zone produced by high yield explosions at the continental margins (Van Dorn Effect). However, because of their dynamic response we expect that the damage potential on SES and ACV's cannot only be restricted to these conditions but must be extended to include the effects of small and moderate yield devices and operations in deep water. It is evident that even under these latter conditions waves can be produced that are capable of limiting the performance of these craft.

The radical differences between the design of these craft and those of present naval ships makes it impossible to extrapolate the results obtained in past studies to the present case. It is only by conducting an investigation, wherein the features of these vehicles are faithfully modeled, that the vulnerability of these craft can be determined.

In light of the above discussion, it is deemed imperative that such a study be conducted with the objective of defining the operational limits of ACV's and SES under explosion generated waves, and to ascertain, where possible, the survival potential of these vehicles when subjected to tactical situations of this nature.

The criteria used in defining the structural design and stability characteristics of SES are derived principally from the desired operational envelopes. The envelope defines the speed-wave height domain over which the craft will operate. Typically, such an envelope is shown in Figure 1.

Two factors which greatly affect the basic structural design of the SES are the highest wave environment to be encountered when operating on-cushion and the maximum impact loading to be seen by the hull during operation. The former factor is of prime importance in selecting the height of the flexible skirt system and thus impacts hull design. The latter determines plating thickness and consequently weight. From Figure 1 it will be seen that point A on the chart determines maximum wave height on cushion. The worst combination of sea state and speed will be determined by line AB along which maximum impact loads are likely to occur. If such an operating envelope is determined without due consideration for potential threats as outlined above grave consequences can arise. It is easily conceivable that a wave environment outside the typical boundaries now being considered in the SES field can be generated by low to moderate yield devices. Such circumstances could cause structural and operational failures.

In addition to the above impacts the question of craft stability and survival are of equal importance. The response of an SES to a typical explosion generated wave profile could lead to conditions of craft plow-in, pitch poling and capsizing. Such

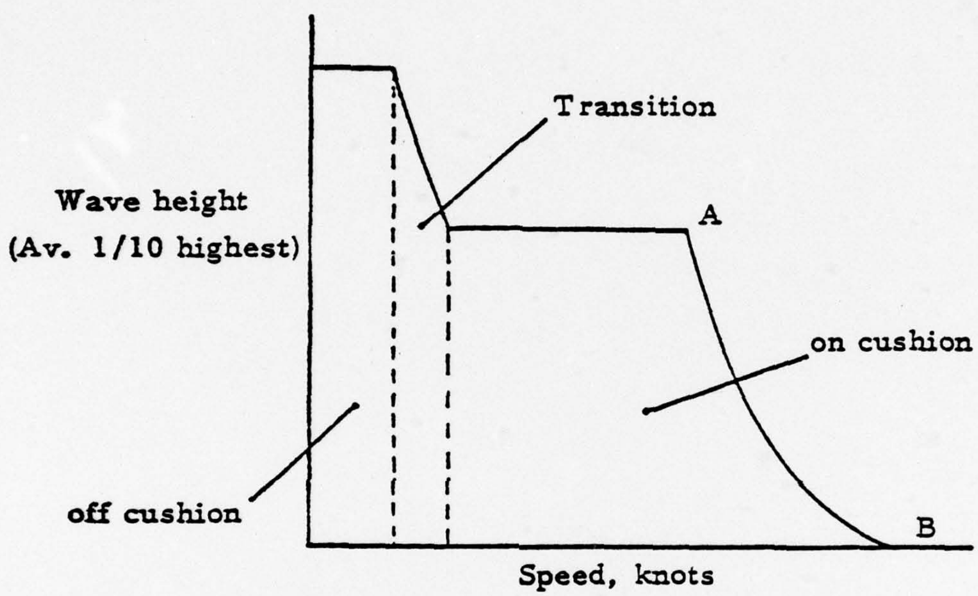

Figure 1: Typical SES operational envelope.

extreme motions are indeed possible under certain conditions of speed, water depth and yield. This aspect of vulnerability is therefore of equal importance in analyzing SES operational characteristics.

The problem at hand can be divided into two basic sub tasks:

(a) The analytical description and modeling of explosion generated water waves, and
(b) The analytical treatment of the craft dynamics and motions when subjected to a disturbing functions as defined in (a) above.

Whereas previously conducted work by Tetra Tech, References 1 and 2, is directly applicable to the first of these areas, the second provides a new and added dimension due to the radical difference between ACV and SES and conventional ships. Analytical modeling of SES motions and maneuvering however, have also been conducted by Tetra Tech, Reference 3 and has been used as a basis of departure for the present program.

The present report deals with the first phase in the investigation of the response of a typical SES to an explosion wave environment. This initial phase has been directed to the formulation and development of the analytical model describing the dynamics of a surface effect vehicle and the description of the explosion generated wave environment. This analytic model has been used to assess the effects of a chosen explosion condition on an SES. Exercise of the program in this area has been limited, pending the start of the second phase which will investigate various parameters of the problem such as the effects of yield, standoff distance, vehicle size, water depth and tactical maneuvers to enhance survival.

In order to fully exercise the analytic program and ensure its validity several cases of sinusoidal waves and solitary waves were also run. These latter waves are representative of waves in the shallow water environment and consequently are worthy of investigation in their own right.

The work described in this report was conducted for the Office of Naval Research under contract N00014-76-C-0261. This report, as already mentioned, covers work during the first phase of the contract and is consequently an interim report.

2. FORMULATION OF PROBLEM

2.1 Coordinate System

The motion of the craft will be described in terms of the relationship between a body fixed reference frame and a co-ordinate system fixed in space. The initial coordinates (x_0, y_0, z_0) and the body coordinates (x, y, z) are both designated according to a right hand convention with z_0 and z positive downward as shown in Figure 2. The origin of the body frame is kept fixed at the center of gravity of the craft for all time, t. The x -axis is parallel to the baseline of the craft, positive forward, and positive y is therefore pointing to starboard. The two coordinate systems coincide initially at time zero.

The body moves with six degrees of freedom; at time t, there will be three linear displacements (surge x, sway y, and heave z) and three angular displacements (roll ϕ, pitch θ, yaw Ψ).

2.2 Kinematic Relations

As the body moves with six degrees of freedom, forces and moments are generated and act on the body. For the convenience of analysis, we shall resolve the total force into three components

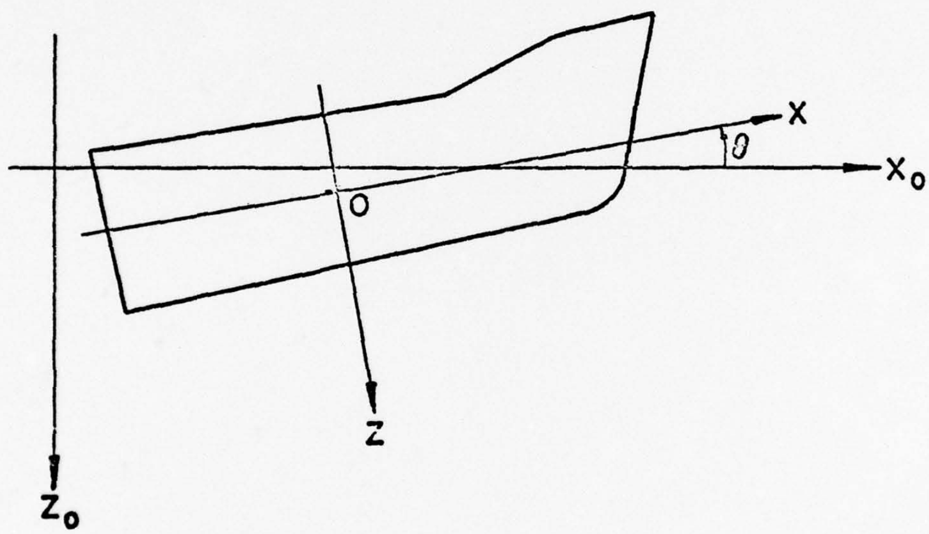

Figure 2: Co-ordinate System.

about the body axes. Definitions and symbols of the six components of force, displacement and velocity are given by Table 1.

TABLE 1

Motion	Force or Movement	Displacement	Velocity
Longitudinal	X	x_1	u
Lateral	Y	y_1	v
Normal	Z	z_1	w
Roll	K	ϕ	p
Pitch	M	θ	q
Yaw	N	ψ	r

It is noted that the linear displacements along the inertial axes have been defined by x, y, and z. These are related to the displacements along the body axes by the following equations:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} =$$

$$\begin{bmatrix} \cos\theta\cos\Psi & \sin\theta\sin\phi\cos\Psi - \cos\phi\sin\Psi & \sin\theta\cos\phi\cos\Psi+\sin\phi\sin\Psi \\ \cos\theta\sin\Psi & \sin\theta\sin\phi\sin\Psi + \cos\phi\cos\Psi & \sin\theta\cos\phi\sin\Psi-\sin\phi\cos\Psi \\ -\sin\theta & \cos\theta\sin\phi & \cos\theta\cos\phi \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} \quad (1)$$

In Table 1, u, v and w are the linear velocities along the body axes, x, y and z, and p, q and r are the angular velocities about these axes respectively.

2.3 Equations of Motion

Consider the craft in six degrees of freedom and let u, v, and w be the linear velocity components of the craft center of gravity along the body axes x, y and z and p, q and r be the angular velocities about these axes, respectively. The equations of motion in this body coordinate system are then given by

$$
\begin{aligned}
m\,(\dot{u} + qw - rv) &= x \\
m\,(\dot{v} + ru - pw) &= y \\
m\,(\dot{w} + pv - qu) &= z \\
Ix\,\dot{p} + (Iz - Iy)\,qr &= K \\
Iy\,\dot{q} + (Ix - Iz)\,rp &= M \\
Iz\,\dot{r} + (Iy - Ix)\,pq &= N
\end{aligned}
\qquad (2)
$$

Where m is the mass and Ix, Iy and Iz are the moments of inertia of the craft about the respective axis. Terms on the lefthand side represent the rigid body inertial reactions and the centrifugal effects acting at the origin with respect to the moving coordinate system. The terms on the righthand side refer to the total forces and moments applied to the craft, including the hydrodynamic effects arising from the overall motions of the craft as well as the results of propulsion and control forces which may affect the craft maneuvers. In a functional form, these components can be expressed generally as:

$$
\left.\begin{matrix} x \\ y \\ z \\ k \\ m \\ n \end{matrix}\right\} = f\,(\dot{u},\dot{v},\dot{w},\dot{p},\dot{q},\dot{r},u,v,w,p,q,r,x_o,y_o,z_o,\phi,\theta,\Psi,\delta,\varepsilon) \qquad (3)
$$

In the above equation, x_o, y_o, and z_o are the position components of the linear displacements of the craft and ϕ, θ, and ψ are the angular displacements. The parameter δ represents a general description of the effect of various propulsion and control schemes, and the parameter ε represents the effect due to the environmental disturbances such as waves. The functional form of the equation shows clearly the dependence of the external force and moment on the various variables. To reduce the above functional relationship into a useful mathematical form, a Taylor expansion is usually applied provided that the linear and non-dimensional proportionality constants, are known or determinable. By keeping a sufficient number of terms for each variable, the forces and moments can be expressed in any desired order of these variables to account for the non-linear effects.

The determination of the proportionality constants, or the hydrodynamic derivatives, by analytical methods is generally limited only to the linear terms. The non-linear coefficients are normally determined experimentally by means of captive model tests. In the present analysis, however, external forces and moments are determined analytically on the basis of physical concepts. While the non-linear coefficients are not explicitly identifiable by this approach, this method is more convenient to include various non-linear features without the backup of experimental information. The general representation of the total force (or moment) acting on an SES is assumed to be composed of various components as follows:

$$
\begin{aligned}
F_i = {} & F_{\text{sidewall } i} + F_{\text{cushion } i} + F_{\text{seals } i} + F_{\text{aerodynamic } i} \\
& + F_{\text{appendages } i} + F_{\text{hydrostatic } i} + F_{\text{propulsion } i} \\
& + F_{\text{control } i} + F_{\text{waves } i}
\end{aligned}
$$

where i = 1 to 6, represents a particular mode or direction of motion. The calculation of each of the component forces is discussed in the following section.

3. FORCES AND MOMENTS - CRAFT DYNAMICS

3.1 Sidehull Forces

The calculation of the forces acting on the sidehulls assumes that these forces fall into two major catagories, namely viscous and non-viscous components. The non-viscous components of forces and moments are those directly related to dynamic fluid pressure resulting from the sidehull motion. These forces are intimately associated with the energy exchanges between the fluid and the moving sidehull and can be deduced from the fundamental principles of classical mechanics. Consequently all non-viscous terms, both linear and non-linear, can be analytically identified as functions of the body added inertia, provided that the non-viscous dissipative damping is negligible. The viscous components are drags created through various origins. The term drag customarily refers to the total resistance of the craft in its axial direction, which consists of many components from many different items, and will be considered in detail separately, in a later section. In the present section, only contributions due to viscous cross flows on the sidehulls are considered. These contributions are normally treated as dependent on the square of the velocity through proportional empirical constants. Some details for the calculation of both the viscous and non-viscous forces on the sidehull are given in the following:

(a) Hydrodynamic pressure on sidewall

Because of the narrow thin geometry, the calculation of the hydrodynamic forces on the sidehull can be performed according

to the fundamental concept of slender body theory. For a slender body of constant speed U in an inviscid, incompressible fluid the linearized free surface condition is given by:

$$U^2 \Phi_{xx} + g\,\Phi_z = 0 \qquad (4)$$

Where Φ is velocity potential. Since the sidehull immersion is normally small in comparison with the craft length, a normalized equation for the above condition can be written as follows:

$$F^2 \frac{d}{\ell} \Phi_{x'x'} + \Phi_{z'} = 0 \qquad (5)$$

Here F is the Froude number based on craft speed and sidehull length. x' is the non-dimensional axial coordinate referenced to the craft length ℓ, and z' is the non-dimensional vertical coordinate referenced to craft immersion d. From the above equation, it is clear that even though F may be large (typically of the order of 1 or 2 for an SES) the fact that the immersion ratio d/ℓ is small (of the order of 10^{-2}) makes the second term dominate. Consequently, the free surface can be regarded as a reflection boundary where:

$$\Phi_{z'} = 0 \qquad (6)$$

which is equivalent to the condition for a positive reflection in the free surface.

The derivation of the boundary condition suggests that the problem can be treated as a body moving in an infinite medium, in which the dissipative damping is negligible. Consequently, as shown by Lamb, reference 4, the hydrodynamic effect on the body is entirely determinable as a function of its added mass along the principal axes of the body. Following the procedure of classical mechanics, the effects of the hydrodynamic pressure on the craft can be obtained.

In deriving the force relations, we shall break the three dimensional sidehull into a number of segments along the longitudinal axis. Each segment will be considered individually as a two-dimensional problem; interferences between segments will be ignored. This is the basic approach of the slender body technique which is adopted in the present analysis.

In so doing, relative fluid velocities at the center of a segment ξ from the normal plane are given by

$$
\begin{aligned}
u_r\,(\xi,t) &= u \\
v_r\,(\xi,t) &= v + \xi r - f\,p \qquad\qquad (7)\\
w_r\,(\xi,t) &= w - \xi q + b\,p
\end{aligned}
$$

where

$$
\begin{aligned}
p &= \dot{\phi} \\
q &= \dot{\theta} \\
r &= \dot{\Psi}
\end{aligned}
$$

and

$$u^2 + v^2 + w^2 = U^2$$

where U is the resultant velocity of the craft o,i,b, and f are the lateral and normal moment arms about the center of gravity respectively. The above relations are applicable to both the starboard and port sidehulls; for the port sidehull however, a negative value of b should be used.

We shall first consider the segment as being axially symmetric and having component added masses m_{yy} and m_{zz} along the lateral and normal axes, respectively. For asymmetrical segments with respect to the axial axis, additional treatment will be considered later.

Specifically, m_{yy} and m_{zz} can be written as follows:

$$m_{yy}(\xi) = k_{yy} \cdot \frac{\pi}{2} \zeta^2(\xi)$$
$$m_{zz}(\xi) = k_{zz} \cdot \frac{\pi}{8} \eta^2(\xi) \tag{8}$$

where k_{yy} and k_{zz} are the added mass coefficients which are generally functions of geometry and frequency; $\eta(\xi)$ is the local beam at the water line and $\zeta(\xi)$ is the local draft.

The added mass component along the axial direction is ignored according to the slender body approach.

The kinetic energy of a unit slice of the fluid can then be written as

$$T(\xi,t) = \frac{1}{2}(m_{yy} v_r^2 + m_{zz} w_r^2) \tag{9}$$

Neglecting the second order terms, the hydrodynamic forces and moments per unit axial length are given by

$$\frac{dY}{d\xi} = - \frac{d}{dt}\left(\frac{\partial T}{\partial v}\right) \tag{10}$$

$$\frac{dZ}{d\xi} = - \frac{d}{dt}\left(\frac{\partial T}{\partial w}\right) \tag{11}$$

$$\frac{dK}{d\xi} = b \frac{dZ}{d\xi} - f \frac{dY}{d\xi} \tag{12}$$

$$\frac{dM}{d\xi} = - \frac{d}{dt}\left(\frac{\partial T}{\partial q}\right) + u \frac{\partial T}{\partial w}, \tag{13}$$

$$\frac{dN}{d\xi} = - \frac{d}{dt}\left(\frac{\partial T}{\partial r}\right) - u \frac{\partial T}{\partial v} \tag{14}$$

The kinetic energy T at a fixed normal plane is a function of ξ and t. The total derivative $\frac{d}{dt}$ therefore must reflect the changing coordinate ξ_n of the normal plane with time. Thus

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \frac{\partial \xi_n}{\partial t}\frac{\partial}{\partial \xi} = \frac{\partial}{\partial t} - u\frac{\partial}{\partial \xi} \tag{15}$$

Substituting (9) into (10) to (14), carrying out the differentiation, and then integrating over the sidewall length, gives the following expressions for the normal and lateral forces and moments acting on the body. In each of these expressions the integrals are taken from stern to bow.

$$\begin{aligned} Z_{nn} = &- (\dot{w} + B\dot{p} + uq) \int m_{zz}(\xi)\, d\xi \\ &+ \dot{q} \int m_{zz}(\xi)\, \xi \, d\xi \\ &+ u\,(w + Bp) \int m_{zz}'(\xi)\, d\xi \\ &- uq \int m_{zz}'(\xi)\, \xi\, d\xi \end{aligned} \tag{16}$$

$$\begin{aligned} M_{nn} = &(\dot{w} + B\dot{p} + uq) \int m_{zz}(\xi)\, \xi\, d\xi \\ &- \dot{q} \int m_{zz}(\xi)\, \xi^2\, d\xi \\ &- u\,(w + Bp) \int m_{zz}'(\xi)\, \xi\, d\xi \\ &+ uq \int m_{zz}'(\xi)\, \xi^2\, d\xi \end{aligned} \tag{17}$$

$$K_{nn} = B\, Z_{nn} \tag{18}$$

$$
\begin{aligned}
Y_{11} = & - (\dot{v} - u\,r) \int m_{yy}(\xi)\, d\xi \\
& - \dot{r} \int m_{yy}(\xi)\, \xi\, d\xi \\
& + \dot{p} \int m_{yy}(\xi)\, f(\xi)\, d\xi \\
& + uv \int m_{yy}{}'(\xi)\, d\xi \\
& + ur \int m_{yy}{}'(\xi)\, \xi\, d\xi \\
& - up \int m_{yy}{}'(\xi)\, f(\xi)\, d\xi
\end{aligned}
\tag{19}
$$

$$
\begin{aligned}
N_{11} = & - (\dot{v} - ur) \int m_{yy}(\xi)\, \xi\, d\xi \\
& - \dot{r} \int m_{yy}(\xi)\, \xi^2\, d\xi \\
& + \dot{p} \int m_{yy}(\xi)\, f(\xi)\, \xi\, d\xi \\
& + uv \int m_{yy}{}'(\xi)\, \xi\, d\xi \\
& + ur \int m_{yy}{}'(\xi)\, \xi^2\, d\xi \\
& - up \int m_{yy}{}'(\xi)\, f(\xi)\, \xi\, d\xi
\end{aligned}
\tag{20}
$$

$$
\begin{aligned}
K_{11} = & (\dot{v} - ur) \int m_{yy}(\xi)\, f(\xi)\, d\xi \\
& + \dot{r} \int m_{yy}(\xi)\, f(\xi)\, \xi\, d\xi \\
& - \dot{p} \int m_{yy}(\xi)\, f^2(\xi)\, d\xi \\
& - uv \int m_{yy}{}'(\xi)\, f(\xi)\, d\xi \\
& - ur \int m_{yy}{}'(\xi)\, f(\xi)\, \xi\, d\xi \\
& + up \int m_{yy}{}'(\xi)\, f^2(\xi)\, d\xi
\end{aligned}
\tag{21}
$$

The first subscript designates the contributing force component and the second subscript stands for the motion direction. For instance, K_{11} represents the rolling moment generated by lateral forces which are induced by lateral motions v_r and $\dot{v}_r$.

It has been mentioned earlier that m_{yy} and m_{zz} are for axially symmetric sections. More often, however, the sidewall sections are asymmetrical. These asymmetrics give rise to cross coupling effects which are estimated as follows:

$$
\begin{aligned}
m_{yz}(\xi) &= k_y \cdot m_{zz}(\xi) \\
m_{zy}(\xi) &= k_z \cdot m_{yy}(\xi)
\end{aligned}
\tag{22}
$$

where $m_{yz}(\xi)$ represents the sectional added mass at station ξ, relating the fluid momentum in the lateral direction y to the local normal velocity in the direction z. Similarly, $m_{zy}(\xi)$ can be interpreted as the added mass relating vertical fluid momentum to the local lateral velocity. The coefficients k_y and k_z are estimated using:

$$k_y = \frac{N_y(\xi)}{N_z(\xi)}$$

where $N_y(\xi)$ and $N_z(\xi)$ are average values of the horizontal and vertical unit normal components of the hull cross-section at any station. The average is taken with respect to the wetted length of the hull cross sectional area. Note that for a side hull with axial symmetry $N_y(\xi)$ is zero and hence there would be no cross coupling forces or moments.

The forces and moments due to cross coupling are then given by:

$$Y_{ln} = k_y \cdot Z_{nn} \tag{23}$$

$$N_{ln} = - k_y \, M_{nn} \tag{24}$$

$$\begin{aligned} K_{ln} = k_y \Big\{ & (\dot{w} + B\,\dot{p} + u\,q) \int m_{zz}(\xi)\, f(\xi)\, d\xi \\ & - \dot{q} \int m_{zz}(\xi)\, f(\xi)\, \xi \, d\xi \\ & - u\,(w + B\,p) \int m_{zz}'(\xi)\, f(\xi)\, d\xi \\ & + uq \int m_{zz}'(\xi)\, f(\xi)\, \xi\, d\xi \Big\} \end{aligned} \tag{25}$$

$$Z_{nl} = k_z \, Y_{ll} \tag{26}$$

$$M_{nl} = - k_z \, N_{ll} \tag{27}$$

$$K_{nl} = B \cdot Z_{nl} \tag{28}$$

(b) Hydrostatic Forces and Moments

The hydrostatic force acting on the body is obtained by integrating the hydrostatic pressure over the entire wetted body surface and is numerically equal to $\rho g \Delta$, where ρ is the density of the fluid, g is the acceleration of gravity and Δ is the volume of the displaced fluid. Let the sectional area at station ξ be $s(\xi)$, which is a function of local draft ζ defined as

$$\zeta(\xi) = D(\xi) + z - \xi \sin\theta + B \sin\phi \tag{29}$$

where $D(\xi)$ is the initial local draft of the body at station ξ.

The total buoyancy force is then given by:

$$F_B = \rho g \int_s^b s(\xi)\, d\xi \tag{30}$$

where the integration is carried from stern to bow. The force component along the body normal axis z is then given by

$$Z_s = -\rho g \cos\theta \int_s^b s(\xi)\, d\xi \tag{31}$$

and the component along the longitudinal axis is

$$X_s = \rho g \sin\theta \int_s^b s(\xi)\, d\xi \tag{32}$$

The hydrostatic pitching moment is given by:

$$M_s = \rho g \int_s^b s(\xi)\xi\, d\xi \tag{33}$$

Similarly, the rolling moment is given by:

$$K_s = -\rho g \int_s^b s(\xi,\zeta) \cdot b(\xi)\, d\xi \tag{34}$$

If b-B is small as compared to B, then approximation of K_s can be simply obtained by

$$K_s = B \cdot Z_s = -\rho g B \int_s^b s(\xi)\, d\xi \tag{35}$$

(c) Axial Drag

The axial drag on the sidehulls arise from two basic sources. Firstly, the frictional drag caused by the viscous effects of the fluid over the body, and secondly the base pressure drag which arises due to the separated wake existing aft of the transom.

The sidehull viscous drag is primarily a function of the Reynolds number and surface finish of the body and is determined from:

$$\text{Drag} = \frac{1}{2} \rho u^2 \, Sw \, C_f \tag{36}$$

where Sw is the wetted surface given by

$$Sw = \int_s^b G(\xi) \, d\xi$$

and $G(\zeta)$ is the girder length at section ζ.

The frictional drag coefficient C_f may be obtained by using the standard ITTC relationship given by

$$C_f = \frac{0.075}{(\text{Log}_{10} Rn - 2)^2} \tag{37}$$

where

$$Rn = \frac{UL}{\nu}\text{, the Reynolds number,}$$

in which

L = sidewall length

ν = kinematic viscosity of fluid.

In addition, a pressure drag component exists on the sidewall; because of the usual design of this type of body being long and slender and having a sharp transom. This can be estimated by an additional drag coefficient given by the following expression:

$$C_B = \frac{0.10}{\sqrt{C_{fB}}} \tag{38}$$

where

C_B = drag coefficient based on base area.

C_{fB} = frictional coefficient based on base area.

This value of drag holds provided the base area is not fully ventilated. At high speeds and/or at shallow immersions the likelihood of ventilation is almost certain. When this occurs, the base drag coefficient is given by

$$C_B = \frac{2}{{F_H}^2} \tag{39}$$

where

F_H = Froude number based on transom immersion

$= \frac{U}{\sqrt{gd}}$

The transition between a fully vented and viscous wake is determined from the following empirically established relation:

if $F_H \geq 3.2$ the base is fully vented.

The force and moment components due to axial drag are thus given by

$$X_a = -\frac{1}{2}\rho u^2 [Sw\ C_f + S(1) . C_B] \tag{40}$$

$$M_a = -\frac{1}{2}\rho u^2 [C_f \int G(\xi)h(\xi)d\xi + C_B\ S(1)f(1)] \tag{41}$$

$$N_a = -B\ X_a \tag{42}$$

where $h(\zeta)$ is the vertical moment arm of the girder at section ζ and $S(1)$ is the immersed transom area.

In addition to the normal components of drag, viz the skin friction drag and the pressure drag, there exists expecially at high speed, a significant spray drag. Unfortunately very little information exists regarding this drag component. However, using the results of some experimental work, references 3 and 5 the spray drag can be expressed in a general form as:

$$D_{spray} = f(q,c,t) \qquad (43)$$

where q is the dynamic pressure, c is the characteristic length from the point of generation of the spray to the maximum thickness point and t is the maximum thickness of the body.

Based on the results of reference 3 the following formulae were obtained for the spray drag caused by a typical SES sidehull configeration:

$$D_{spray} = 0.75\ C_f\ qct \qquad (44)$$

In this formula the value of t is taken to be the maximum thickness in the waterline plane and the friction coefficient C_f is evaluated at the appropriate Reynolds number.
This result has shown excellent agreement with the test results.

(d) Viscous cross-flow effect

As mentioned this component of the sidehull forces and moments is a non-linear term arising due to the real fluid effects occurring on the sidehull. The contribution of this term to the overall force on the sidehull is small for small excursions of the hull but becomes the dominant term as craft motions become greater. This force is usually cast in the form:

$$\text{Cross-flow forces} = \tfrac{1}{2}\rho C_D S \left|V_r\right| V_r \tag{45}$$

where C_D = cross flow drag coefficient
S = projected area of the sidehull
V_r = relative flow velocity

The coefficient C_D is a function of geometrical shape of the body and Reynolds number. It is usually obtained from experimental data by judicial interpretation of the results from tests done on idealized geometric shapes.

Accordingly, the forces and moments due to this effect are given by:

$$Z^C_{nn} = -\frac{\rho}{2}(C_D)_{nn}\int \eta(\xi)\,|w_r|\,w_r\,d\xi \tag{46}$$

$$M^C_{nn} = \frac{\rho}{2}(C_D)_{nn}\int \eta(\xi)\,|w_r|\,w_r\,\xi\,d\xi \tag{47}$$

$$K^C_{nn} = B\,.\,Z^C_{nn} \tag{48}$$

$$Y^C_{ll} = -\frac{\rho}{2}(C_D)_{ll}\int D(\xi)\,|v_r|\,v_r\,d\xi \tag{49}$$

$$N^C_{ll} = -\frac{\rho}{2}(C_D)_{ll}\int D(\xi)\,|v_r|\,v_r\,\xi\,d\xi \tag{50}$$

$$K^C_{ll} = \frac{\rho}{2}(C_D)_{ll}\int D(\xi)\,|v_r|\,v_r\,f(\xi)\,d\xi \tag{51}$$

In addition to these terms there are also cross coupling terms arising due to these cross flow drag forces. These forces are given by:

$$Y^C_{ln} = k_{yc}\;Z^C_{nn} \tag{52}$$

$$N^C_{ln} = -k_{yc}\;M^C_{nn} \tag{53}$$

$$K_{ln}^{C} = \frac{\rho}{2} k_{yc}(C_D)_{nn} \int \eta(\xi) |w_r| w_r f(\xi) d\xi \tag{54}$$

$$Z_{nl}^{C} = k_{zc} Y_{ll}^{C} \tag{55}$$

$$M_{nl}^{C} = - k_{zc} N_{ll}^{C} \tag{56}$$

$$K_{nl}^{C} = B \cdot Z_{nl}^{C} \tag{57}$$

where the superscript C designates cross flow, and the subscripts have the same meaning as defined previously.

The value of the cross coupling coefficients k_{yc} and k_{zc} in this case are taken to be proportional to the cotangent of the local deadrise angle of the sidehull at any given section.

3.2 Cushion Pressure Forces

In addition to the forces imparted to the craft through the sidehulls, the cushion pressure supporting the craft has a significant effect on the craft dynamics. For the present investigation, since a general type of craft is being considered, the supporting air cushion is considered as basically a rectangular box bounded by the sidehulls and the forward and aft seals. The plenum is fed by a fan, or system of fans, with a specified fan characteristic. Details of the fan ducting and heave alleviation devices which are usually used on such craft have not been included in the analysis as this would require a more detailed definition of the lift fan system, a task beyond the scope of the present preliminary study.

The basic equation governing the air flow into and out from the cushion is the conservation of mass which states that

$$\dot{m} = \rho \, (Q_{in} - Q_{out}) \tag{58}$$

where $\dot{m}$ = rate of change of mass in the plenum

Q_{in} = total flow into the plenum
Q_{out} = leakage flow out under the seals and sidehulls

The flow into the air plenum is governed by the lift fan characteristic which is represented by:

$$Q_{in} = Q_f = \phi_o + \phi_1 p_c + \phi_2 p_c^2 \tag{59}$$

where $\phi_o, \phi_1\ \phi_2$ are constants
p_c = cushion pressure

The leakage flow is considered to be governed by an orifice type flow equation given by:

$$Q_{out} = C_O A_L \sqrt{\frac{p_c - p_a}{\rho}} \tag{60}$$

where C_O = discharge coefficient
ρ = density
p_a = atmospheric pressure
p_c = cushion pressure
A_L = leakage area

The leakage area in this equation is comprised of several components. These can be represented as

$$A_L = A_O + A_{sw} + A_s \tag{61}$$

where A_O = equilibrium leakage flow
A_{sw} = leakage flow under the sidehull
A_s = leakage flow under the seals

The above equilibrium leakage flow is that leakage required to maintain the craft at a given equilibrium condition when not disturbed by any waves. This leakage area can be adjusted by changing the setting of the seals under actual conditions and it determines the equilibrium immersion of the craft. The equilibrium pressure is obviously given by

$$(p_c - p_a) A_c = W - F_B \tag{62}$$

where W = craft weight

F_B = buoyancy force

A_c = plenum area

The areas A_{sw} and A_s are obtained at each instant in time by integrating the clearance between the sidehull and seals with respect to the local water elevation.

This leakage area obviously changes as a function of time depending on the craft motions and the free surface elevation.

The pressure in the plenum is assumed to vary according to an adiabatic compression law, viz

$$(p_c + p_a) V^{\gamma} = \text{constant} \tag{63}$$

where V = plenum volume.

From the conservation of mass equation the following equation can be obtained,

$$\dot{V} = Q_{in} - Q_{out} \tag{64}$$

on substituting, $m = \rho V$.

Using the above equations the pressure and flows into the plenum can be found and the resulting forces and moments on the craft can be calculated as follows:

$$Z_{pres} = (p_c - p_a)\ A_c \tag{65}$$

$$Y_{pres} = (p_c - p_a)\ A_c\ B \tan \phi \tag{66}$$

$$X_{pres} = (p_c - p_a)\ A_c\ l \tan \theta \tag{67}$$

$$M_{pres} = X_{pres}\ (VCG - \frac{l}{2} \tan \theta) \tag{68}$$

$$K_{pres} = -Y_{pres}\ (VCG - \frac{B}{2} \tan \phi) \tag{69}$$

where VCG = vertical height of CG above keel

B = Width of the plenum

ϕ = roll angle

l = length of the plenum

In addition to the above forces, the pressure acting on the free surface causes a wave drag effect which has to be accounted for in the computations. The wave drag has been discussed extensively in the literature.

The wave drag referred to here includes that due to the sidehulls, the pressure planform, and their interactions. The calculations for the wave resistance of a pressure patch and a pair of thin walls is straight forward provided that the geometrical form is simple. Following the method of reference 6, the total wave resistance for a combination of a pressure planform and two sidehulls in a channel of width W can be written as follows:

$$R_w = \sum_{m=0}^{\infty} \epsilon_m \frac{1 + \sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}}{\sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}} (P^2 + Q^2) \tag{70}$$

where

$$P + iQ = \frac{k_o^{\,2}}{4\rho g W} \iint_S p_o(x,y) \exp\left[i k_o b_m x + i 2\pi y \frac{m}{W}\right] dx dy$$

$$+ \frac{16\pi^2 \rho k_o}{W} \iint_D \sigma(x,z) \exp[k_o b_m (b_m z + i x)] \cos 2\pi y_1 \frac{m}{W} dx dz$$

$$\epsilon_m = \begin{array}{l} 1 \text{ for } m = 0 \\ 2 \text{ for } m \geq 1 \end{array}$$

$p_o(x,y)$ = Pressure distribution on planform S

k_o = g/V^2

g = gravitational acceleration

V = Ship speed

ρ = density of water

$\sigma(x,y)$ = singularity distribution for representation of sidehull D

y_1 = distance of sidehull center plane from the craft centerline

$$b_m = \sqrt{\frac{1}{2} + \frac{1}{2}\sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)}}$$

Considering that the pressure planform is rectangular and the sidehulls are of parabolic shape, the above integrals can be evaluated easily and the results have been given by:

$$R_w = \frac{1}{2}\rho V^2 L^2 \sum_{m=0}^{\infty} \epsilon_m \frac{1 + \sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}}{\sqrt{1 + \left(\frac{4\pi m}{k_o W}\right)^2}} \quad X$$

$$\cdot \left\{ \frac{8B_1}{L} \frac{1}{k_1\sqrt{k_o W}} \cos\left(2\pi \frac{B}{L} \frac{m}{W_1}\right) \cdot \frac{1-e^{-b_m^2 k_o H}}{b_m^2} \right.$$

$$\left[\frac{1}{b_m} \cos(k_1 b_m) - \frac{\sin(k_1 b_m)}{k_1 b_m^2}\right] - 2\frac{L}{B}\sqrt{\frac{k_1}{W_1}}$$

$$\left.\left(\frac{\overline{W}}{\rho g L^3}\right) \sin(k_1 b_m) \sin\left(2\pi \frac{B}{L} \frac{m}{W_1}\right) \Big/ \frac{\pi m}{W_1} \right\}^2 \tag{71}$$

where

$k_1 = k_o L/2$

$W_1 = W/L/2$

$\overline{W}$ = total weight of the craft = $p_o BL$

B = bubble width

L = bubble length

B_1 = sidewall width

3.3 Seal Forces

For purposes of the present study a very simplified seal configuration has been adopted. Again, this has been done in order to avoid too many detail points which would reflect a given design rather than a general craft.

The present seals are assumed to be flexible fabric seals, such as a bag and finger design, which when immersed in the water simply deflect and lie on the water surface. Hence they do not contribute any forces or moments to the craft except for their axial drag and the forces and moments arising due to the shift in the center of pressure of the air in the plenum caused by

the changing imprint length on the water. Referring to figure 3, which shows a simple bow seal, the following equations can be derived:

$$Z \text{ seal} = (p_c - p_a) \text{ lw } B \tag{72}$$

$$M \text{ seal} = Z \text{ seal ls} \tag{73}$$

where $\text{lw} = \text{ls} \dfrac{\tan \theta}{\sin \theta_B}$

ls = distance of seal tip to C.G.

θ_B = sheer angle of seal

θ = trim of craft

the axial drag due to the seal is:

$$X \text{ seal} = C_f \frac{\rho}{2} V^2 \text{ lwB} \tag{74}$$

where C_f is the friction factor, derived from the Reynolds number as follows:

$$C_f = \frac{0.044}{R_e^{1/6}} \tag{75}$$

R_e is the Reynolds number based on the seal wetted length lw.

3.4 Aerodynamic Forces

The aerodynamic forces and moments acting on the craft have been simplified and are represented by an overall drag coefficient based on frontal area of the craft. This drag coefficient has been selected to correspond to test results on SES type configurations. The force is therefore simple:

$$X \text{ aero} = C_D \frac{1}{2} \rho V^2 A_f \tag{76}$$

where A_f = frontal area of craft.

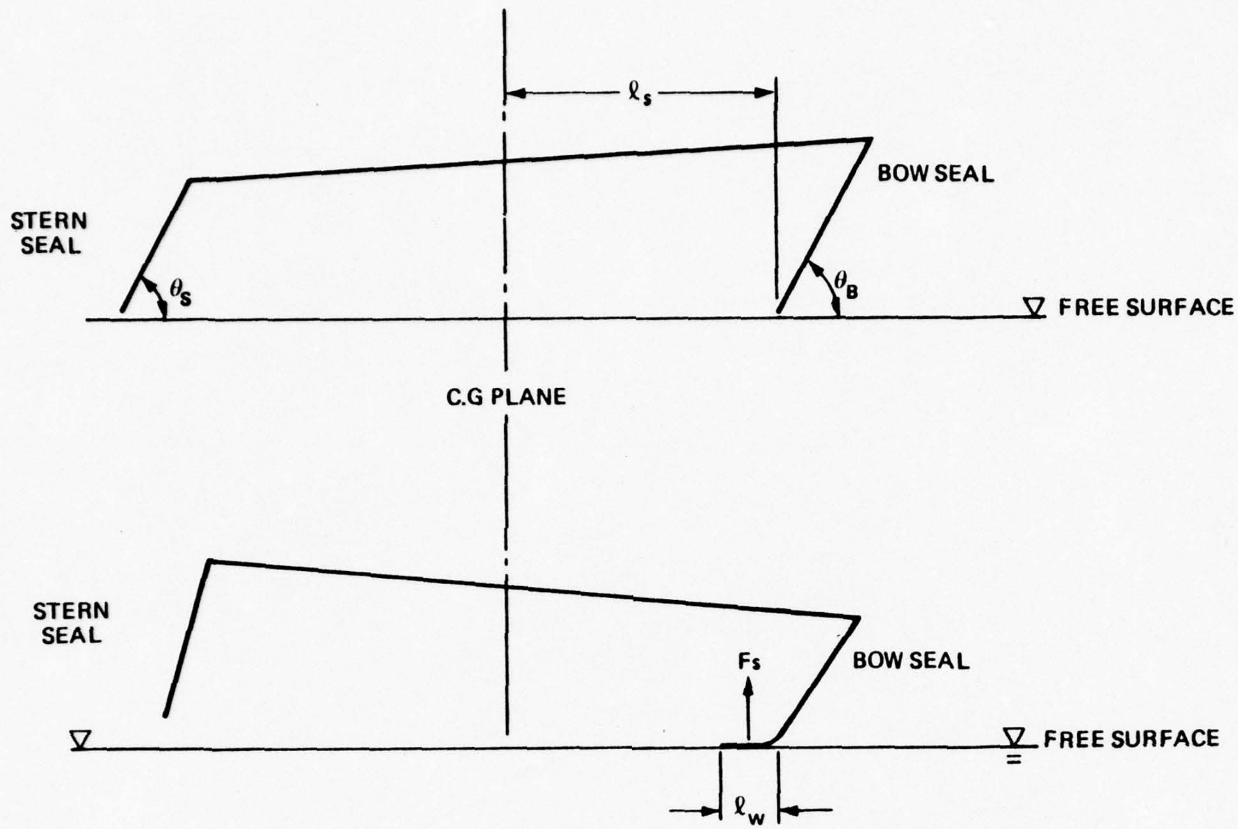

Figure 3: Schematic of Seal Force

No aerodynamic lift or moments have been used in the present study as the craft is operated in a straight line course at all times and no wind conditions are considered, consequently only an axial aerodynamic force exists.

3.5 Propulsion and Control Forces

Various methods of propelling and controlling the craft exist. Current emphasis for SES propulsion is a waterjet. These devices allow for thrust vectoring or differential thrust for maneuvering and turning. Since we are only considering straight line operation in the present study no such devices will be considered. The methodology used is to calculate the drag for a given immersion and trim at a specified speed and allow the thrust to be equal to the calculated drag. As the craft responds to the wave environment its attitude and draft will be varying causing changes in drag and cushion pressure. The thrust, however is kept constant to the initially calculated value thus slight surge motions will occur during the time the craft encounters the waves.

3.6 Appendages

Usually, especially in the case of an SES, directional stabilizers or fins are fitted in order to ensure directional stability. Standard representations of these appendages exist in the program code developed, which account for drag and lift forces. In the present study a nominal fin has been assumed.

These items are considered as base vented parabolic sections designed to produce the required lateral stiffness to the craft to ensure stability. For present purposes, therefore, two items attributing to the total drag of these fins, namely pressure drag and frictional drag, are considered.

Since the quality of these surfaces has to be kept smooth and constantly clean to ensure cavitation free operation, it is assumed that for all intents and purposes the surface is close to being hydrodynamically smooth and consequently the frictional drag is computed on this basis. The total drag of the stabilizer surface can then be written as:

$$D_{fin} = \tfrac{1}{2}\,\rho V^2 A\,[C_d + 2\,C_f] \qquad (77)$$

where

A = fin surface area, ft^2

C_d = pressure drag coefficient

C_f = frictional drag coefficient

For a base venting parabolic section we have

$$C_d = \frac{\pi}{8}\left(\frac{t}{c}\right)^2$$

where

$\frac{t}{c}$ = thickness-chord ratio

and, for a smooth surface the frictional coefficient can again be approximated by the formula:

$$C_f = 0.044/Rc^{1/6} \qquad (78)$$

where

Rc = Reynolds number based on mean chord.

The lift force from the fin is calculated using the following classical lift equation.

$$Y_{fin} = \frac{1}{2} \rho V^2 A C_L \tag{79}$$

where

$C_L = 2\pi \frac{AR}{AR+3}$

AR = Aspect ratio of the fin.

V = Relative velocity of the fin in the water.

4. WAVE ENVIRONMENT

4.1 Wave Representation

The computation of explosion generated waves can be divided into three parts; they are the modeling of the source condition, the calculation of propogation and transformation of waves over a given bottom topography, and the determination of breaking inception and wave run-up according to some acceptable criteria. The last two parts would involve tedious bookkeeping of propagation history from point to point, should the bottom topography be irregular. Since the study in the current phase emphasizes specifically the mathematical modeling of the craft, the details of the bottom irregularities are not considered. If the continental shelf is assumed two-dimensional and to have a constant mild slope, the wave environment can simply be classified into two characteristically different groups; deep water and shallow water waves.

4.2 Deep Water Wave Generation

The deep water waves theoretically can be represented by sinusoids of various frequencies. While the craft responses in sinusoidal waves are to provide a general indication of the craft characteristics as a function of wave period, they provide little information as to

how the craft responds when it is sufficiently close to the source region, as the wave amplitudes are normally very large such that the linear superposition technique is not valid and applicable. The present model is capable of simulating either a sinusoid wave system or an idealized explosion-generated wave system at a given stand-off distance from the source at any time after detonation. Whereas the sinusoidal wave form is simpler and well-known, only modeling of the explosion-generated waves is discussed in the following:

The problem concerning waves generated by an arbitrary but localized disturbance on a free surface has been investigated by Kajiura, reference 7. In analyzing the explosion-generated waves, the initial disturbance is usually assumed as being of a parabolic crater-like shape with radial symmetry such that:

$$\bar{\eta}(r) = \eta_o \left[2({}^{r}/R_o)^2 - 1\right] \quad \text{for } r \leq R_o \qquad (80)$$
$$= 0 \quad \text{for } r > R_o$$

where η_o = crater height
R_o = crater radius
r = radial distance

The waves resulting from this disturbance at a distance r from the center are then given by, Van Dorn et al, reference 8, as

$$\eta(r,t) = \frac{\eta_o R_o}{r} \left[- \frac{V/k}{dV/dk} \right] J_3 (kRo) \cos (kr-\omega t) \qquad (81)$$

where k = wave number, determinable from the relationship, between the group velocity V and the arrival time t, such that

$$V(k) = \tfrac{1}{2} \frac{\omega}{k} \left(1+ \frac{2kd}{\text{sink } 2kd}\right) = \frac{r}{t}$$

$$\omega = \sqrt{gk \tanh kd}$$

d = water depth
J_3= Bessel function of the 1st kind of order 3.

The above equation shows that the traveling wave train possesses a series of amplitude peaks primarily governed by the moderating Bessel function J_3. The problem that remains is to relate the crater dimension η_o and R_o to the yield of a given explosion so that prediction of waves at a given location r and time t can be made.

It is noted that both η_o and R_o are not easily measurable. What one can measure are the wave height and period at a large distance from the source disturbance. It is in fact more convenient to measure the amplitude peak η_{max} in the first wave envelop at a given range r, and the corresponding wave number k_{max} can be evaluated by knowing the arrival time t from the above equations. Analytically, one can show that, for a particular source disturbance $\bar{\eta}$ (r), the amplitude of the maximum wave η_{max} is inversely proportional to r, and the corresponding wave number k_{max} is independent of the crater height η_o. For an explosion in sufficiently deep water, k_{max} can be determined from the first stationary value of J_3 as:

$$k_{max} R_o = 4.2$$

Once the measurement of k_{max} is obtained, the crater radius can be readily estimated. From equation (81), one finds:

$$\eta_o R_o = 1.63 \, \eta_{max} r \quad .$$

when $k = k_{max}$. Consequently, the crater height can also be estimated from the measurement of wave height.

Empirical correlations of measurements of η_{max} with the explosion yield W and the detonation depth Z show that there is a certain trend between the parameter $\eta_{max} r/W^{0.54}$ and the parameter $Z/W^{0.3}$ (W in lbs of TNT equivalent); this is best presented graphically

by plotting the experimental data points as shown in Figure 5. It is noted that there are two peaks appearing in the former parameter over a range of the latter. One of these peaks occurs at $Z/W^{0.3} = -0.05$ and is commonly termed as the upper critical depth. Detonation at this depth is seen to produce the highest responses. The other peak occurs at $Z/W^{0.3} = -2.7$ and is usually called as the lower critical depth.

As discussed before, the parameter k_{max} can be determined by measuring the arrival time of the first wave at a given distance. By analyzing the wave profiles obtained from the measurements, an empirical relationship between the parameter k_{max} and yield might W has also been established, namely:

$$\begin{aligned} k_{max} &= 0.44\ W^{-0.3} \quad \text{for } 0 > Z/W^{0.3} \geq -0.25 \\ &= 0.39\ W^{-0.3} \quad -0.25 > Z/W^{0.3} \geq -7.5 \end{aligned} \tag{82}$$

Using these empirical relations together with the measured results as shown in Figure 5, the source parameters η_o and R_o can be determined for any yield at any water depth and detonation depth. Consequently, the wave history at any point r and time t can be calculated according to equation (81).

4.3 Shallow Water Waves

Two types of waves should be considered with regard to shallow water waves. Firstly, those waves produced in deep water as a result of an offshore explosion which transform their height, shape and internal characteristics through the process of shoaling, refraction and reflection when they propagate shoreward into shallower water. Secondly, waves directly generated by explosions in shallow water on the continental shelf. As far as the wave characteristics are concerned, these waves can be considered

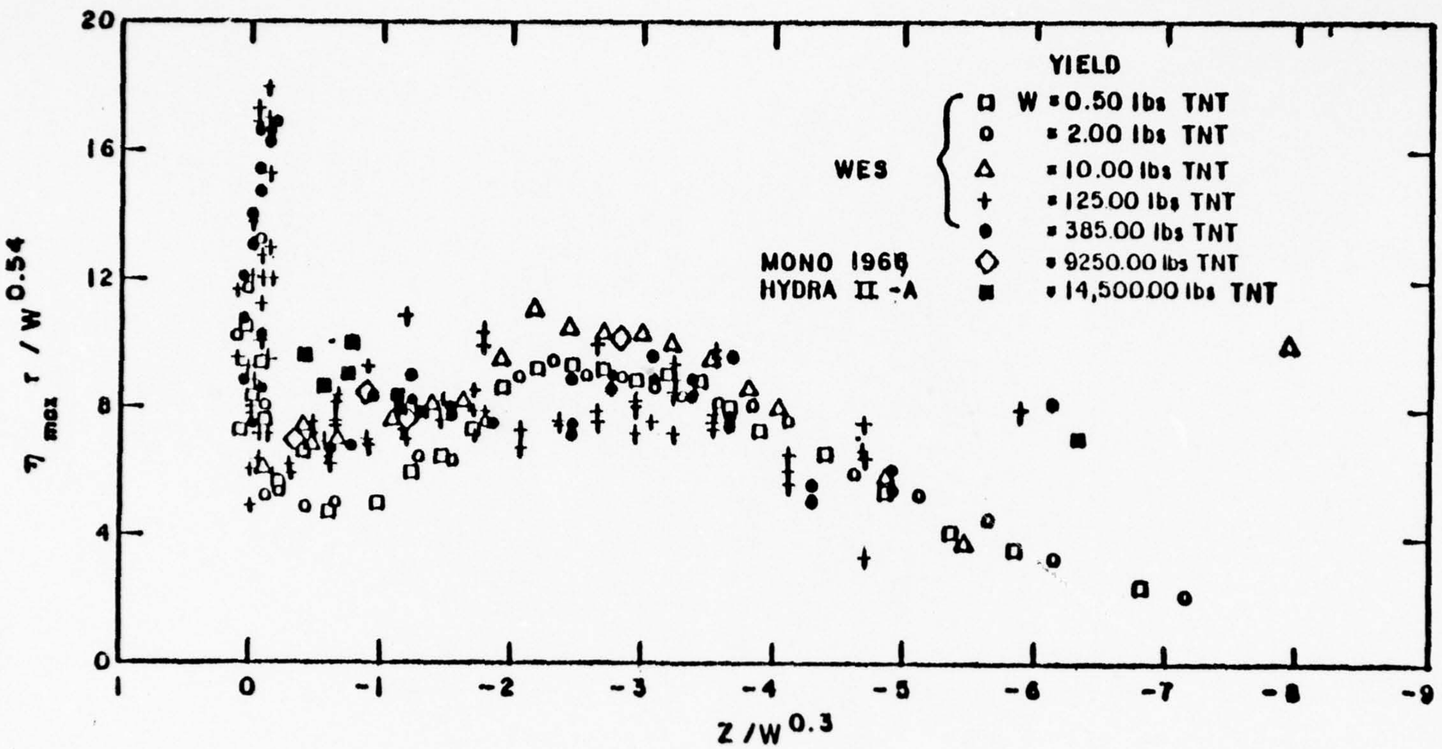

Figure 5 An Empirical Scaling Fit Relating Values of η_{max}, Charge Depth and Explosion Yield (data provided by Waterways Experiment Station).

identical and be treated in a similar manner. Before entering into the discussion of how to model these waves mathematically, however, correlations of yield with wave generation in shallow water are briefly outlined below.

The method of correlation between wave heights and yields discussed in the previous section is limited to deep water wave generation such that $d > 6\,W^{0.3}$. For explosions in water of depth such that $1 < {}^{d}/W^{0.3} < 6$, Le Méhauté, reference 9, proposed a simple interpolation rule to fit the experimental data, as follows:

$$\eta = \eta_{deep}\left[\tfrac{1}{2} + \frac{1}{10}\left(\frac{d}{W^{0.3}} - 1\right)\right] \tag{83}$$

This shows that the generation efficiency is reduced by half when the parameter $d/W^{0.3}$ approaches unity. In the case of very shallow water where $d/W^{0.3} \ll 1$, the linear model is no longer valid and different correlations must be used. Unfortunately, there are very few data collected of shallow water explosions. Among the available data as listed in Table 2, only the WES test data, reference 10, provide systematic variations of charge weight and water depth.

By means of small-scale charges (0.5 -2048 lbs.) the WES program was designed to estimate wave effects due to a 20 KT explosion in water of 30 to 200 feet deep. The charge position varied from beneath the bottom to above the free surface. The results showed that variations of Z/d from -1.0 to 0 had little effect on wave height. In contrast to deep water explosions, the most significant parameter for wave generation in shallow water is water depth, instead of charge position.

The other significant feature is that the dispersion law is different for waves propagating in deep and shallow water. In

TABLE 2

EXPERIMENTAL DATA

			BAKER[2]	MONO LAKE I[3]	MONO LAKE II[3]	WES[1]
EXPLOSIVES			NUCLEAR	TNT	TNT	TNT
CHARGE WEIGHT	W	(lbs)	4.6×10^7	9.2×10^3	9.2×10^3	0.5 - 2048
WATER DEPTH	d	(ft)	180	14	10	0.07 - 7.43
DETONATION DEPTH	Z	(ft)	90	10	10	
$\frac{d}{W^{1/3}}$			0.5	0.67	0.47	0.088 - 0.585

[10] WES (1955)
[11] Glasstone, S. (1962)
[12] Garcia, W.J. (1970) (U)

deep water, wave height varies inversely with radial distance r as a combined result of frequency and radial dispersions. In extremely shallow water, the large leading wave is expected to behave like a solitary wave so that its height varies inversely as $r^{2/3}$ instead of r. In moderately shallow water, the relation below should hold

$$\eta \, r^{\beta} = \text{constant} \qquad 2/3 \leq \beta(d) \leq 1 \tag{84}$$

In correlating the WES test data, the following empirical formula is derived

$$\frac{\eta_{max} \; r^{\beta}}{W^{\beta/3 + 0.25}} = 1.44 \left(\frac{d}{W^{1/3}}\right)^{0.93} \tag{85}$$

where $\beta = 0.83 \left(\frac{d}{W^{1/3}}\right)^{0.07}$

It is noted that the power β varies as a function of the depth parameter $d/W^{1/3}$; for the very shallow case, β approaches $^{2/3}$ as a limit. While the derivation of the above realtionship has assumed that reasonable extrapolation of the WES data is valid, it must be noted that the correlation is based upon the experimental data covering $d/W^{1/3}$ up to 0.585. There is no indication that it will approach the empirical relation (83) as d increases.

Equation (85) provides an empirical relationship for predicting the maximum wave height at any distance r from a shallow water explosion. After the wave height is determined for a given explosion, the important procedure required for numerical simulation is a mathematical representation of the wave history as a function of time. As mentioned earlier, disregarding whether the waves are generated in shallow water or are propagated into shallow water from offshore, their internal characteristics are approximated identical if their height and period are the same.

The most important parameter which affects these waves in this case is the local water depth. As is well known, when waves propagate into shallower water, their crests become more peaked through shoaling. When the local depth d becomes so shallow that the wave height $h \simeq 0.67\ d$ to $0.78\ d$, waves start to break. Analytical and experimental studies of wave propagation and transformation have been discussed in detail by Le Méhauté et al, reference 13, and Divoky et al, reference 14. Their analyses show that, among many existing wave theories, the cnoidal wave theory is good for describing the transition from deep water waves to shallow water waves but the solitary wave theory best describes the long, shallow water waves including the spilling type breakers. In the present study, the solitary wave form is used for numerical modeling of the long period waves on the continental shelf. After the wave height and period is determined according to the yield weight, the mathematical representation of the waves in water of depth d is given by

$$\eta\ (x,t) = h\ \mathrm{sech}^2\ \alpha(x-ct) \tag{86}$$

where

h = wave height

$\alpha = \sqrt{3h/4d^3}$

$c = \sqrt{gd}\ (1+ h/_2d)$

5. NUMERICAL TECHNIQUES

The computer program developed to integrate the equations of motions under the influence of the forces and moments inputed to the craft by the wave environments described previously will now be briefly discussed.

Initiation of the computation is made by entering into the program the initial conditions of the craft such as altitude, speed and craft weight. Overall craft dimensions and the geometry of the

sidehulls and seals are also required. With the above information the submerged geometry of the sidehulls and seals are calculated and the forces and moments from all sources described in section 3 are calculated. The initial values of all the variables are then used as starting values at time t=0, to initiate integration of the equations of motion.

A fourth order Runge Kutta scheme is used for the integration and all variables are updated at each time step. Time steps of the order of 0.1 seconds are normally used.

The wave field is also started at t=0 and, depending on the particular case being considered, propagates towards the craft in a predetermined direction (heading). Three options are currently available for the wave field, as previously discussed. Experienced gained with the program indicates that runs vary typically from about 15 seconds to 70 seconds when using a CDC 6600.

An overview flow chart illustrating the general operations performed in the computer is shown in figure 5.

6. RESULTS

The program was exercised under various wave conditions and craft headings to investigate, on a preliminary basis, the response of a typical SES. In order to conduct this study several assumptions had to be made regarding the craft size and dimensions. In order to make the results relevant to current interests an SES having characteristics similar to the 2000 ton class was chosen. Some of the salient features of this craft are listed below:

Craft weight = 2000 lng tons
Cushion length = 240 feet
Cushion beam = 88 feet

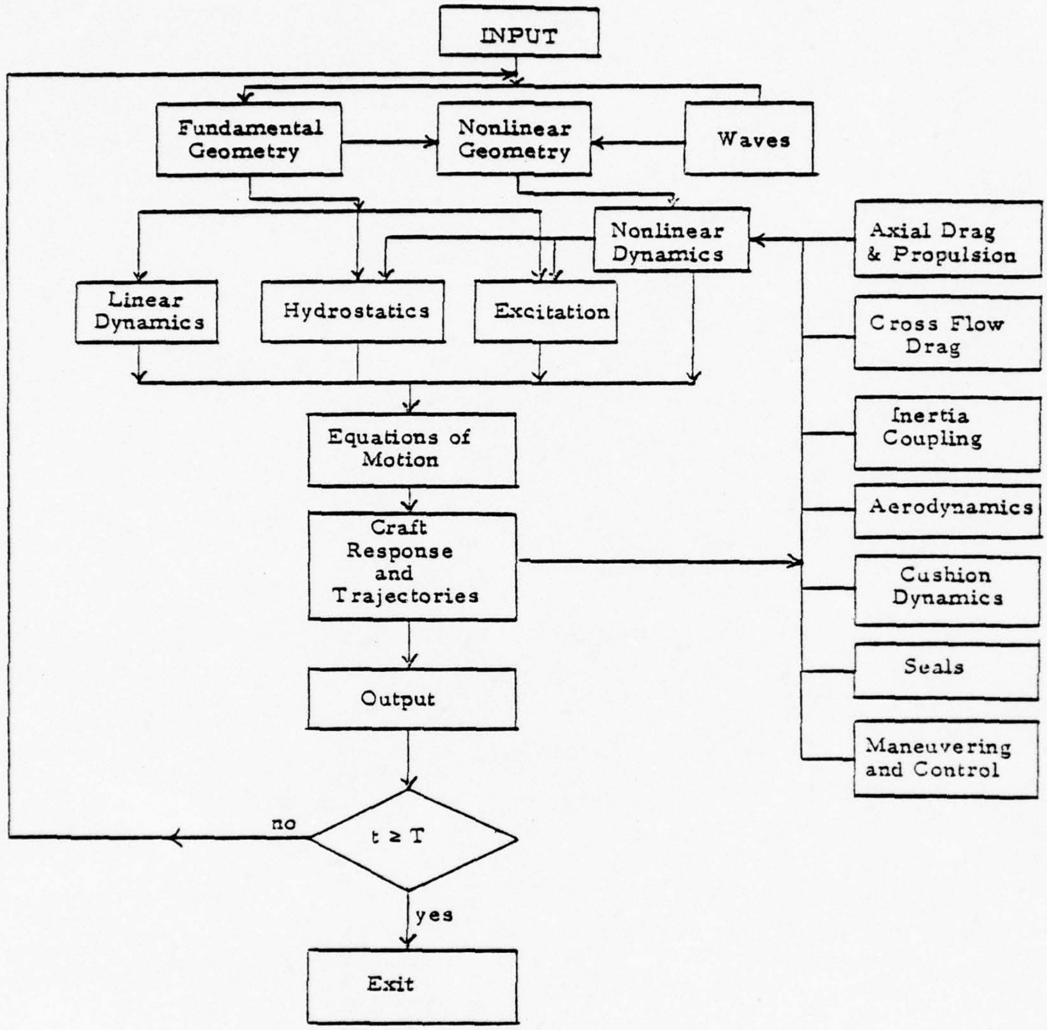

Figure 5 Flow Chart of Computer Code.

Center of Gravity location = 130 ft. forward of transom
24 ft. above keel

Lift fan characteristic:

$$Q_f = 75,497 - 121 (p_c - p_a) \text{ cfs}$$

Bow seal angle = 30°

Stern seal angle = 60°

Initial air leakage area = 49 ft.^{2}

The definitions of inputs and a sample input case are shown in Appendix A. This input provides further information, including details of the sidehull shapes chosen. This shape is also representative of typical sidehull designs for SES.

The results of these runs are shown in the following figures.

6.1 Sinusoidal Wave Response

In order to exercise the program and obtain a reference base of craft response a series of runs was conducted using a sinusoidal wave excitation. This wave was chosen to correspond to the significant wave height and period of a Sea State 3 Pierson Moskowitz spectrum, namely:

Wave height = 5 feet

Period = 6 seconds

Figures 6 through 9 illustrate the results of these runs for heading angles of 0°, 45°, 165° and 180°, respectively. In these figures the cushion pressure and wave profile are shown in the upper figure; the pitch and yaw in the middle and the heave response and roll in the lower diagram. The curves are shown as a function of a non-dimensional time, t/T. The required conversion factor to real time is given in each caption. For these specific runs the craft immersion at the center of gravity was 1.9 feet at a initial trim of 0.9 degrees.

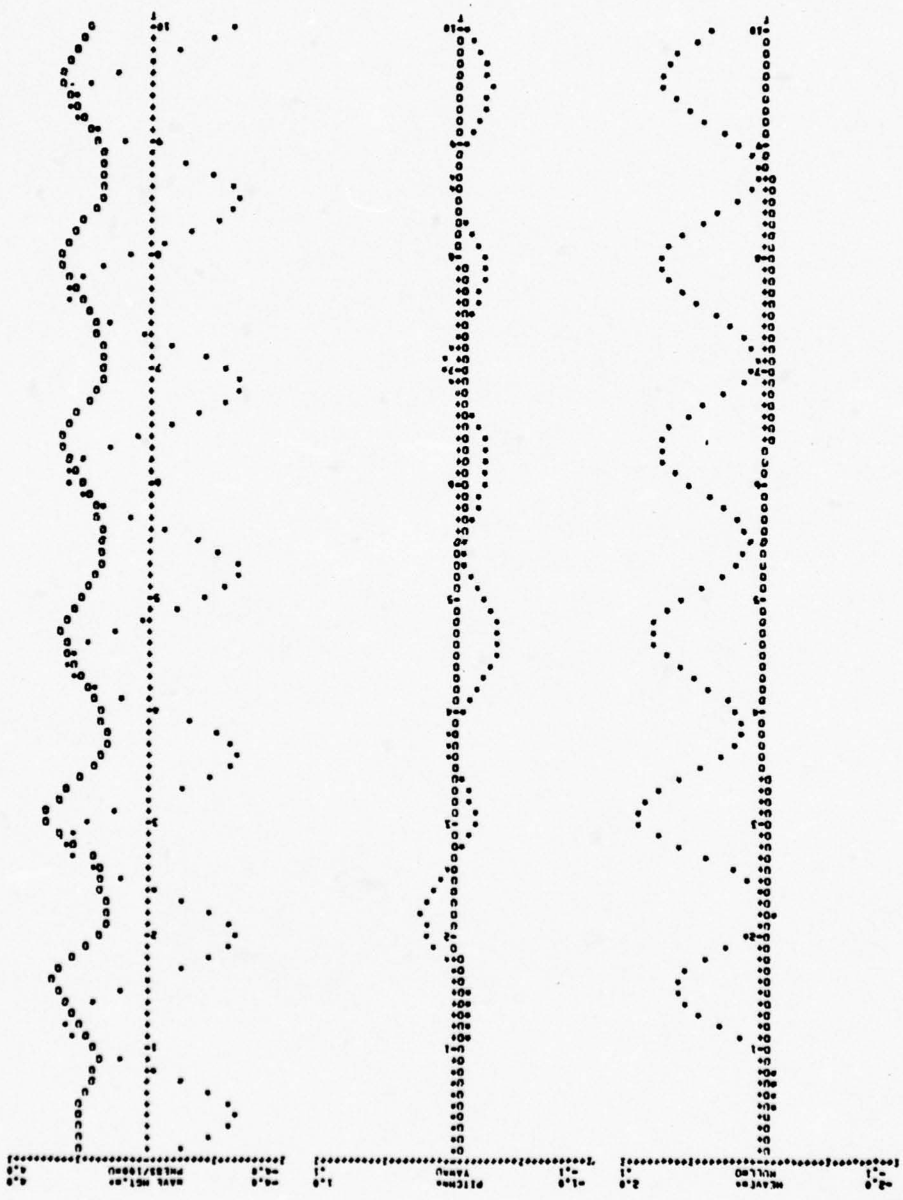

Figure 6 Craft Response in Sea-State 3 - average wave height = 5 ft, average wave period = 6 sec, craft speed = 80 knots, craft heading = 0 deg $\frac{t}{T}$ = 1.10 sec

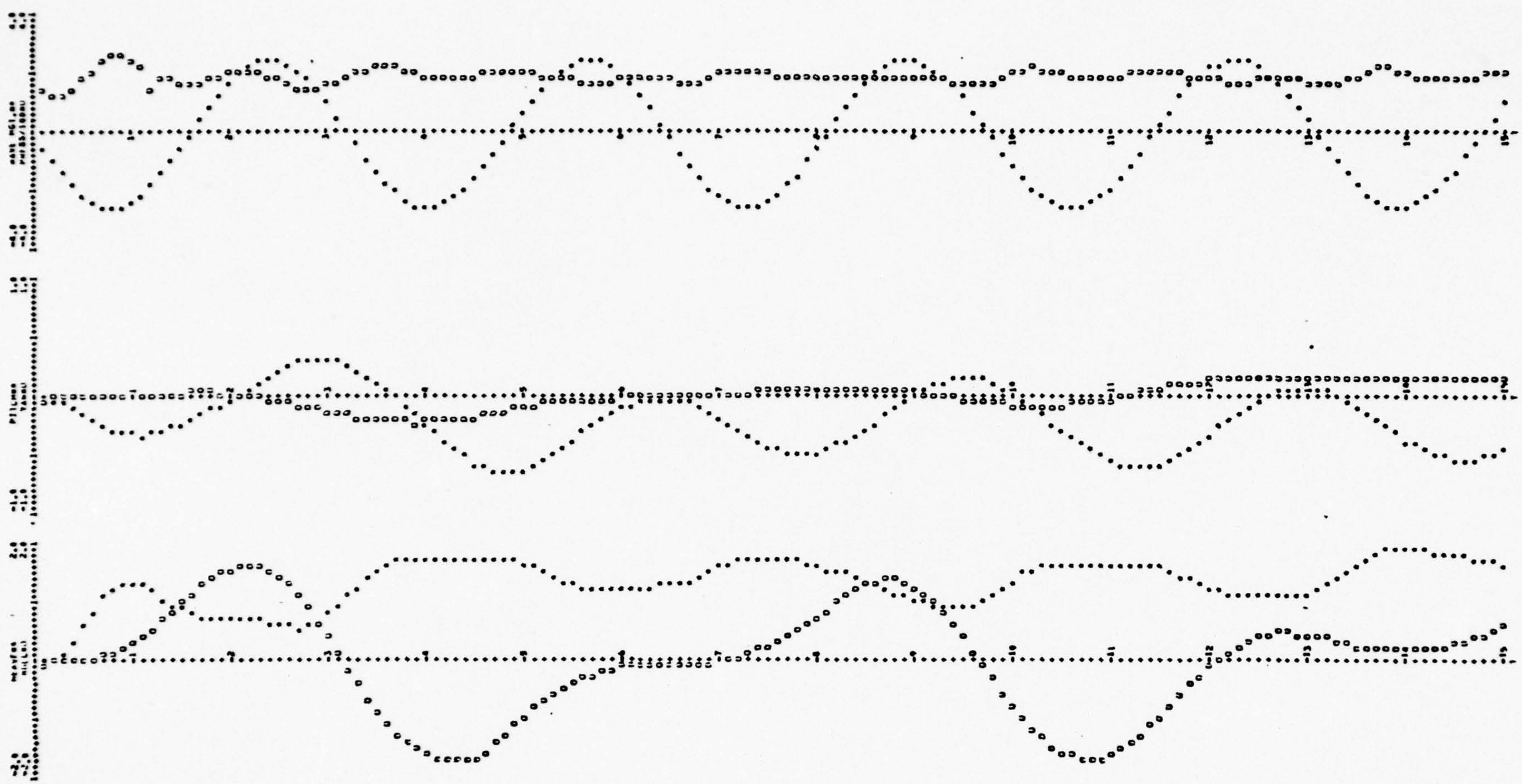

Figure 7 Craft Response in Sea-State 3 - average wave height = 5 ft, average wave period = 6 sec, craft speed = 80 knots, craft heading = 45 deg $\frac{t}{T}$ = 0.89 sec

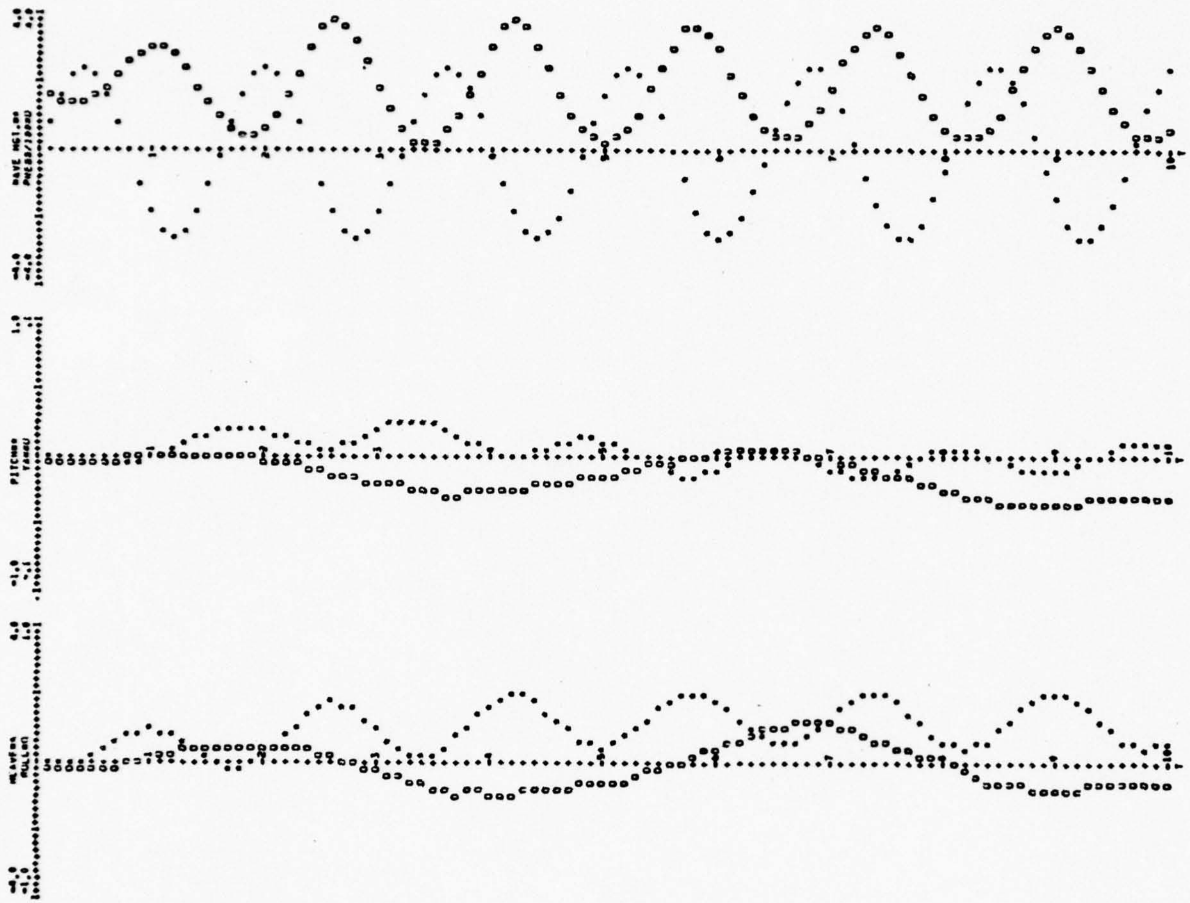

Figure 8 Craft Response in Sea-State 3 - average wave height = 5 ft, average wave period = 6 sec, craft speed = 80 knots, craft heading = 165 deg $\frac{t}{T}$ = 0.72 sec

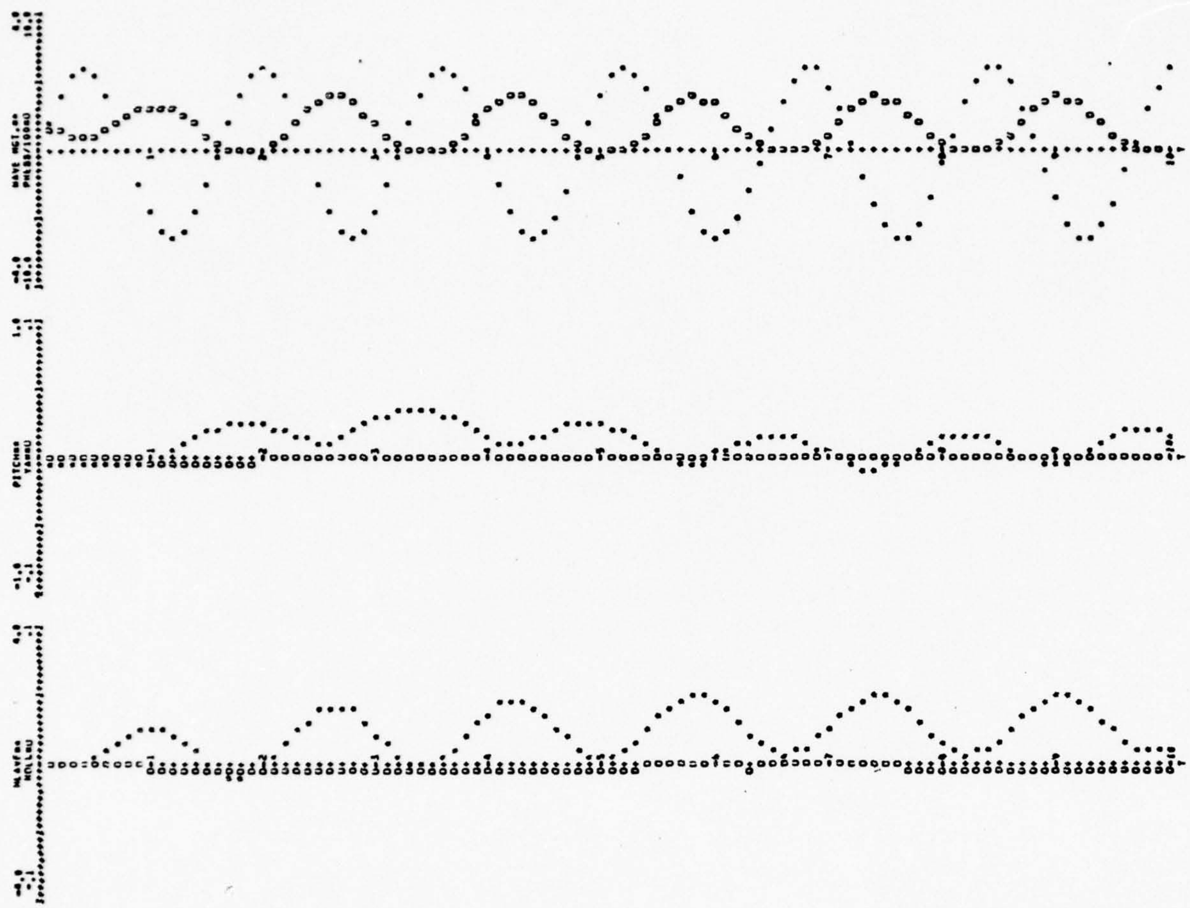

Figure 9 Craft Response in Sea-State 3 - average wave height = 5 ft, average wave period = 6 sec, craft speed = 80 knots, craft heading = 180 deg $\frac{t}{T}$ = 0.70 sec

It will be seen from these results that generally the craft is well behaved in this sea state. However, in the cases of 165° and 180° heading fairly large oscillations occur in cushion pressure with corresponding heave excursions. These two runs, which deal with head seas, illustrate that the cushion pressure is certainly more responsive to head seas than to the following seas, shown in figures 6 and 7.

It should be emphasized, however, that no heave alleviation devices have been modelled in the present program and consequently this type of behavior is not unexpected. It is anticipated that installation of such a device would alleviate this situation considerably.

The cases with quartering seas, namely figures 7 and 8 show roll and yaw responses. In particular figure 7 shows a roll amplitude of approximately 2°. This case, run for a quartering following sea, also shows an increased pitch response which is to be expected. The wave length to cushion length ratio for these runs is 1.29 which is removed from the wave pumping value of 2.0. It should also be pointed out that the natural frequency of the craft under the above initial trim and heave conditions is approximately:

Pitch natural frequency = 1.45 Hertz

Heave natural frequency = 1.67 Hertz

6.2 Solitary Wave Response

As discussed in section 5, within the continental margins in shallow water, the waves caused by deep water explosion can be represented by solitary waves. In this section we have conducted a series of runs wherein the craft response to a solitary wave at various headings has been investigated. Furthermore, the effect of varying water depth and wave height is also shown.

For the present runs the initial trim and center of gravity immersion was taken to be 1 degree and 2 feet, respectively. The runs were performed at a craft speed of 50 knots, except for one run which was conducted in a near hovering mode. (actual speed was 5 knots.) The wave height and period were varied during this series and are identified in the caption of each figure.

The hovering condition is shown in figure 10. As will be seen in this run the water depth is taken as 60 feet with a wave period of 15 seconds and wave height of 6 feet. With these conditions the ratio of wave length to cushion length is 2.91. Behavior of the craft is quite acceptable with the maximum pitch and heave excursions shown in Table 3.

The effects of varying heading angle for the conditions described in the above case are shown in figures 11, 12 and 13. As will be seen from these runs, all at 50 knots, the pitch excursions increase as the heading varies from a beam sea condition to a head sea. Attendant with this change in heading the roll and yaw decreases. In the case of 90° heading or beam seas the roll motion is excited at a natural frequency of about 1.34 Hertz. It is apparent from these curves that the craft will survive this wave environment without undue difficulty. It should be pointed out that whereas it may appear desirable to head away from a blast situation, should one occur, the results would depend on the craft relative velocity to the wave. This approach for reducing wave induced damage may or may not be appropriate.

Figures 14, 15 and 16 illustrate the behavior of the craft under differing combinations of wave height, water depth and wave period for a head sea i.e., heading of 180°. The exact conditions are given in Table 3. In the first two cases, figures 14 and 15, craft response is reasonable although some relatively large heave and pitch excursions occur in the 10 foot wave condition.

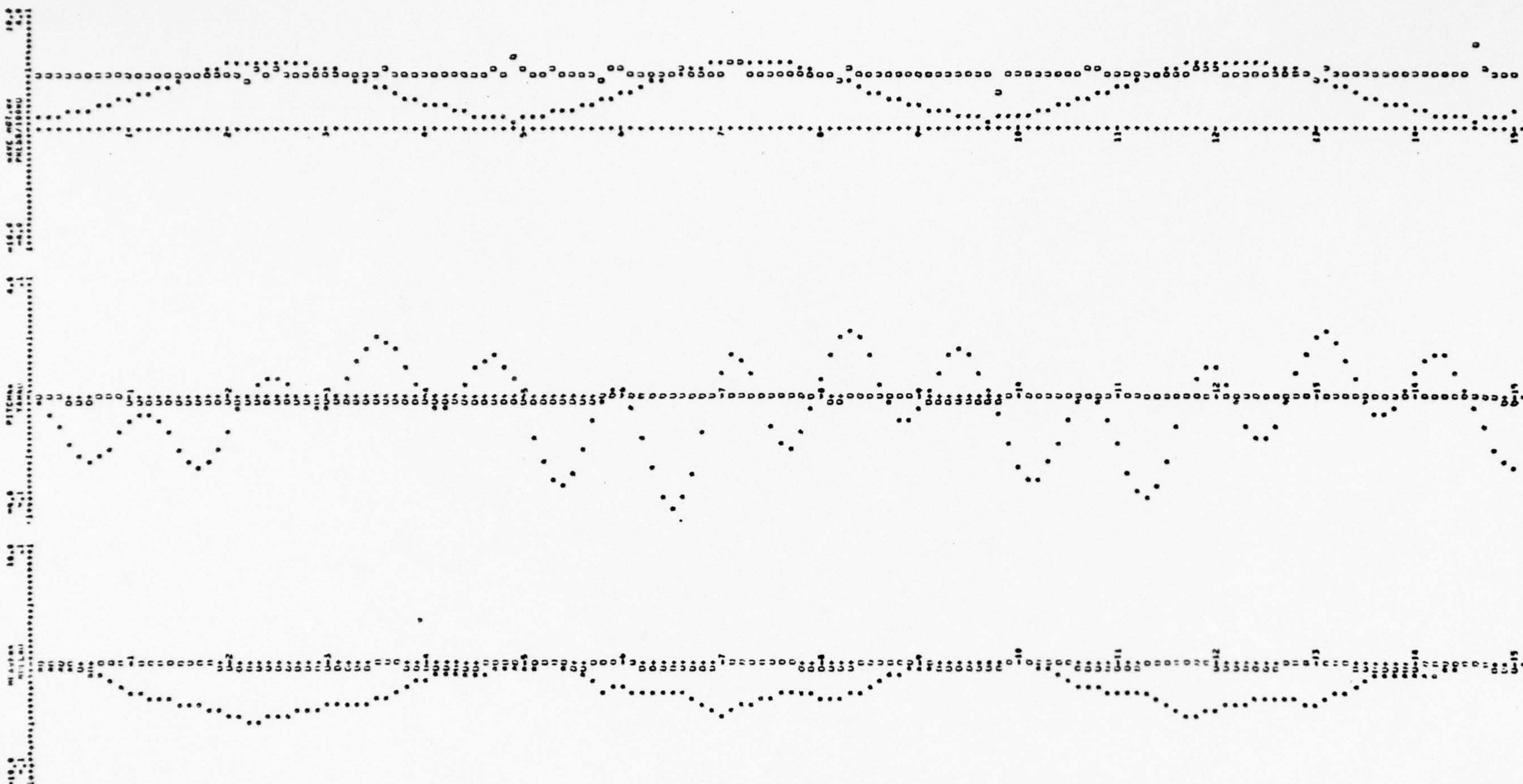

Figure 10 Craft Response in Shallow Water - water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 0 (hovering), craft heading = 0 deg, $\frac{t}{T}$ = 3.82 sec

TABLE 3

Solitary Wave Results

Period = 15 sec. Wave Height = 6 ft. Depth = 60 ft. λ/L = 2.91

Heading (Deg)	Speed (Knots)	Maximum			Max. Heave (Ft)
		Trim (Deg)	Roll (Deg)	Yaw (Deg)	
0	0	-3.61	0	0	-4.7
90	50	-0.31	+5.10	-2.7	-5.0
135	50	-1.97	+4.19	-0.89	-4.48
180	50	-3.69	0	0	-4.72

Period - 30 sec. Wave Height = 10 ft.Depth = 60 ft. λ/L = 6.01

180	50	-5.37	0	0	-8.08

Period = 30 sec. Wave Height = 5 ft. Depth = 30 ft. λ/L = 4.25

180	50	-3.55	0	0	4.46

Period = 15 sec. Wave Height = 6.5 ft.Depth = 30 ft. λ/L = 2.18

180	50	-5.78	0	0	7.90

Note: Heading angle defined as 0° for following seas, 180° for head seas.

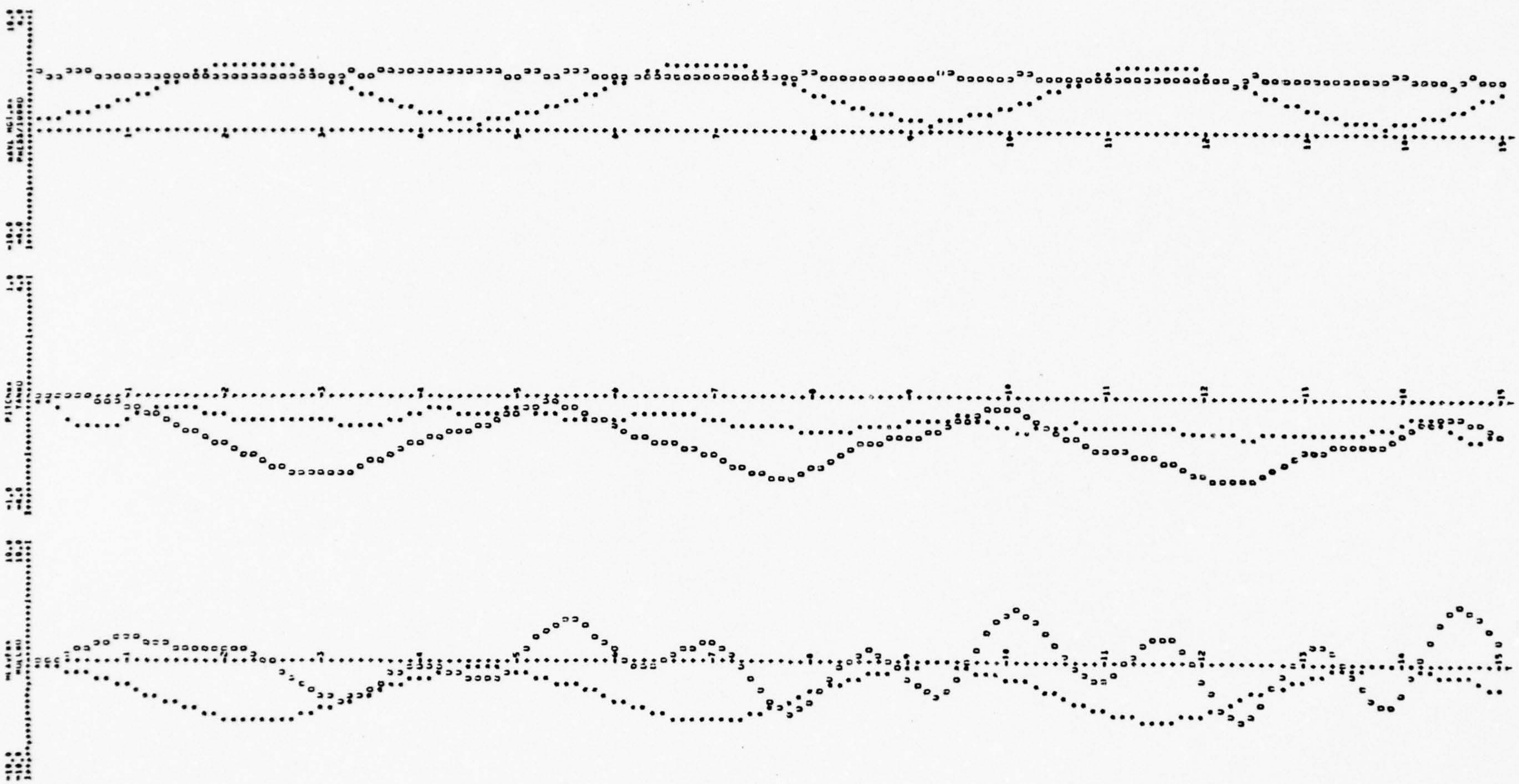

Figure 11 Craft Response in Shallow Water - water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 50 knots, craft heading = 90 deg, t/T = 3.12 sec

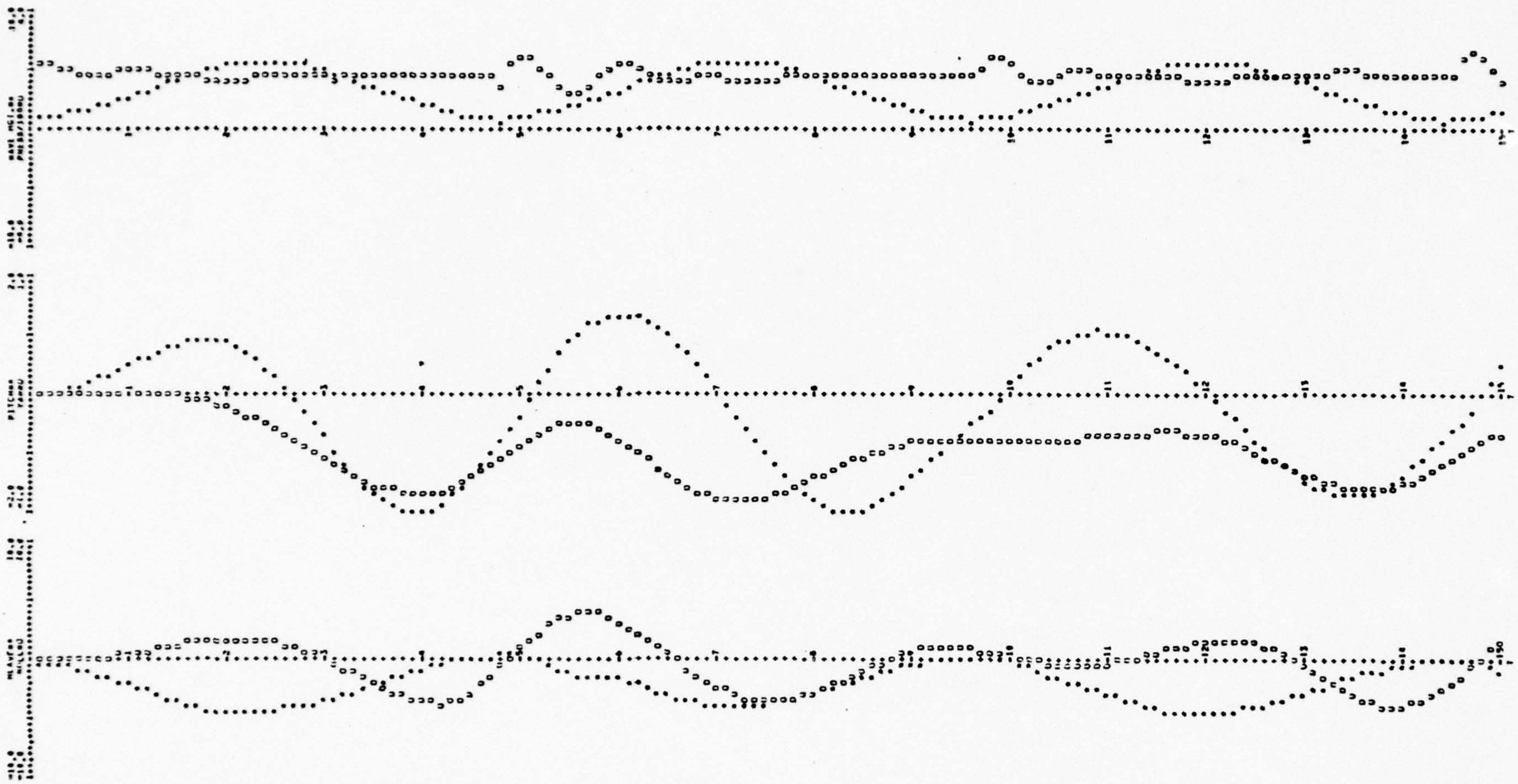

Figure 12 Craft Response in Shallow Water, water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 50 knots, craft heading = 135 deg, $\frac{t}{T}$ = 1.36 sec

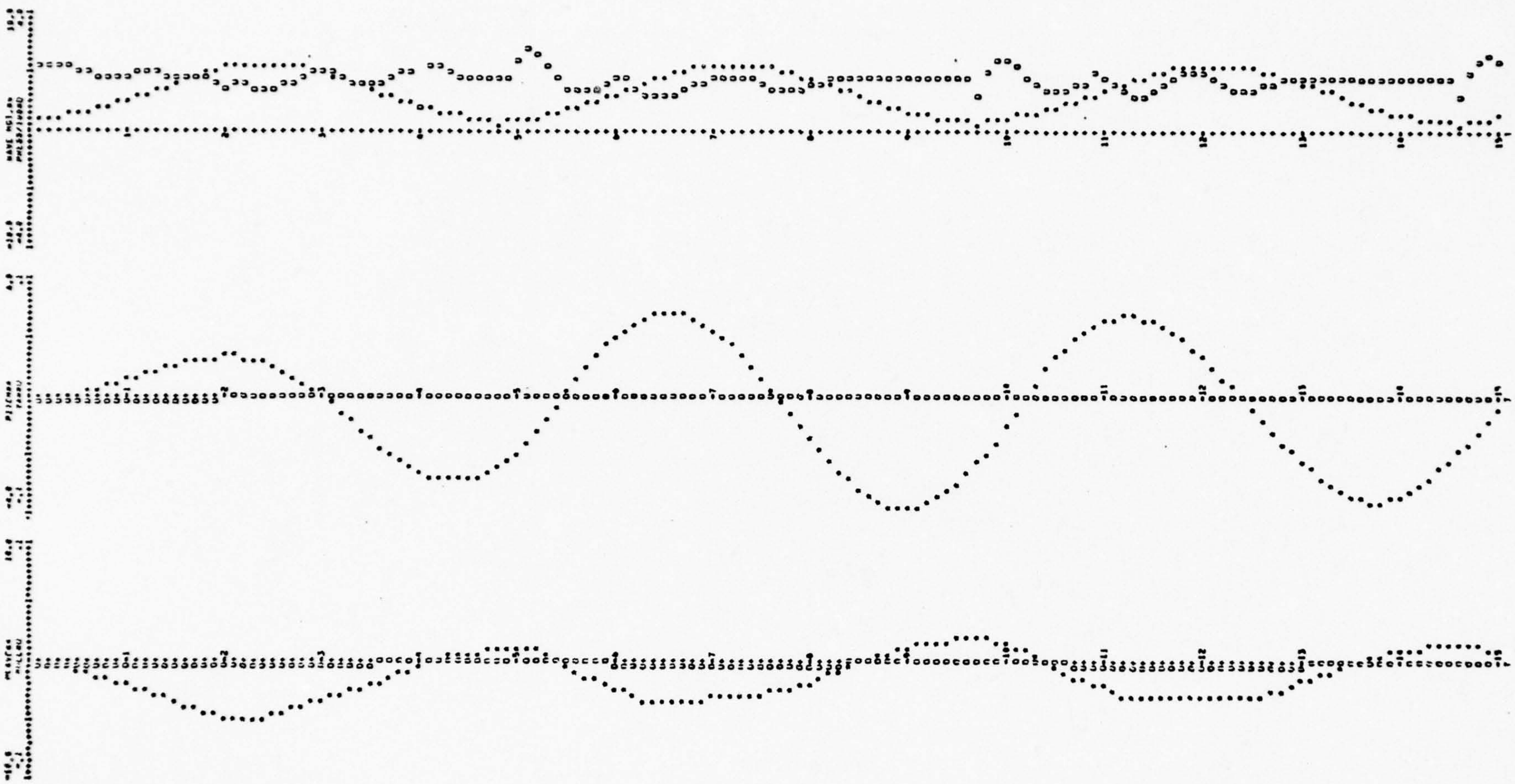

Figure 13 Craft Response in Shallow Water - water depth = 60 ft, wave period = 15 sec, wave height = 6 ft, craft speed = 50 knots, craft heading = 180 deg, $\frac{t}{T}$ = 1.10 sec

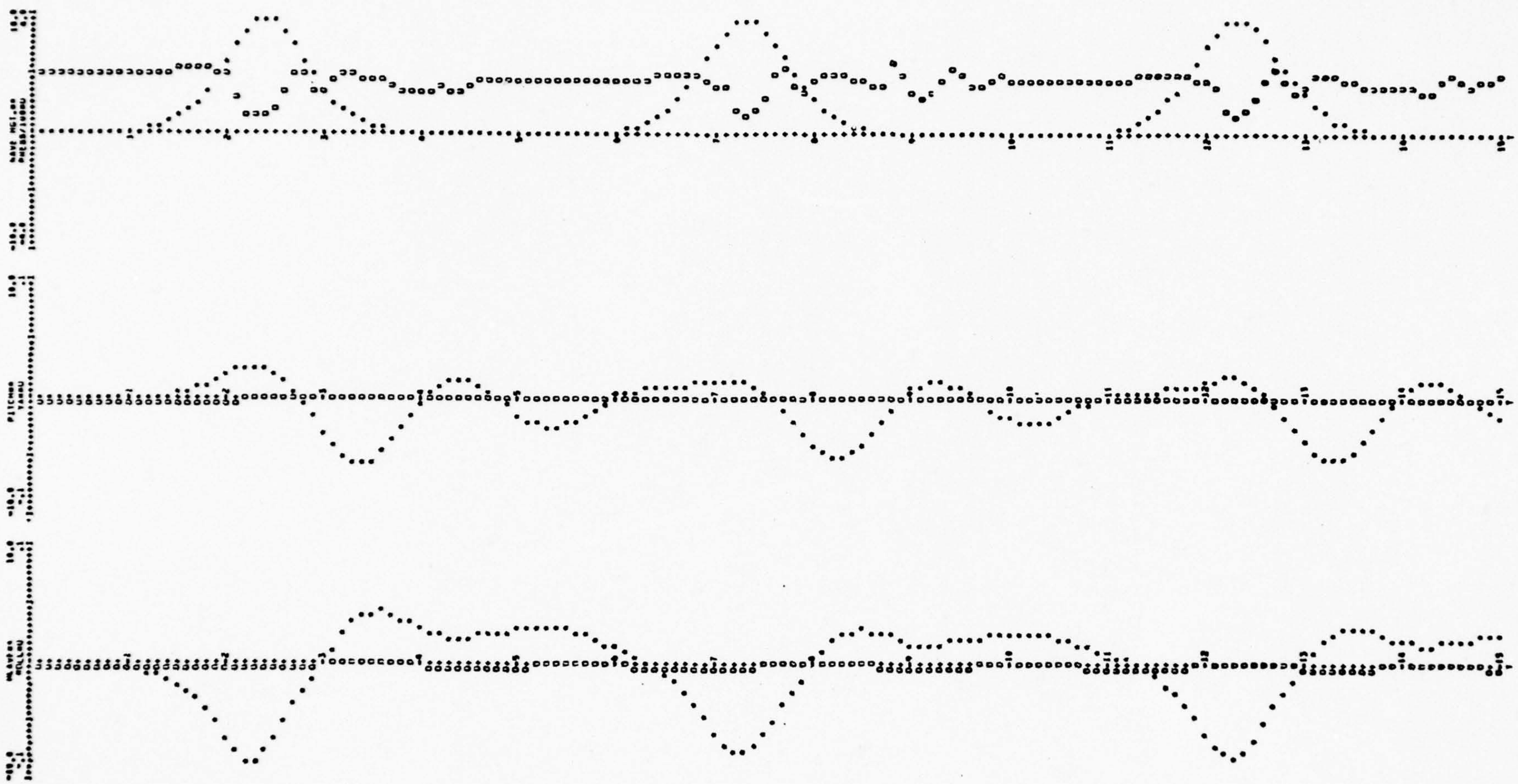

Figure 14 Craft Response in Shallow Water - water depth = 60 ft, wave period = 30 sec, wave height = 10 ft, craft speed = 50 knots, craft heading = 180 deg, $\frac{t}{T}$ = 2.25 sec

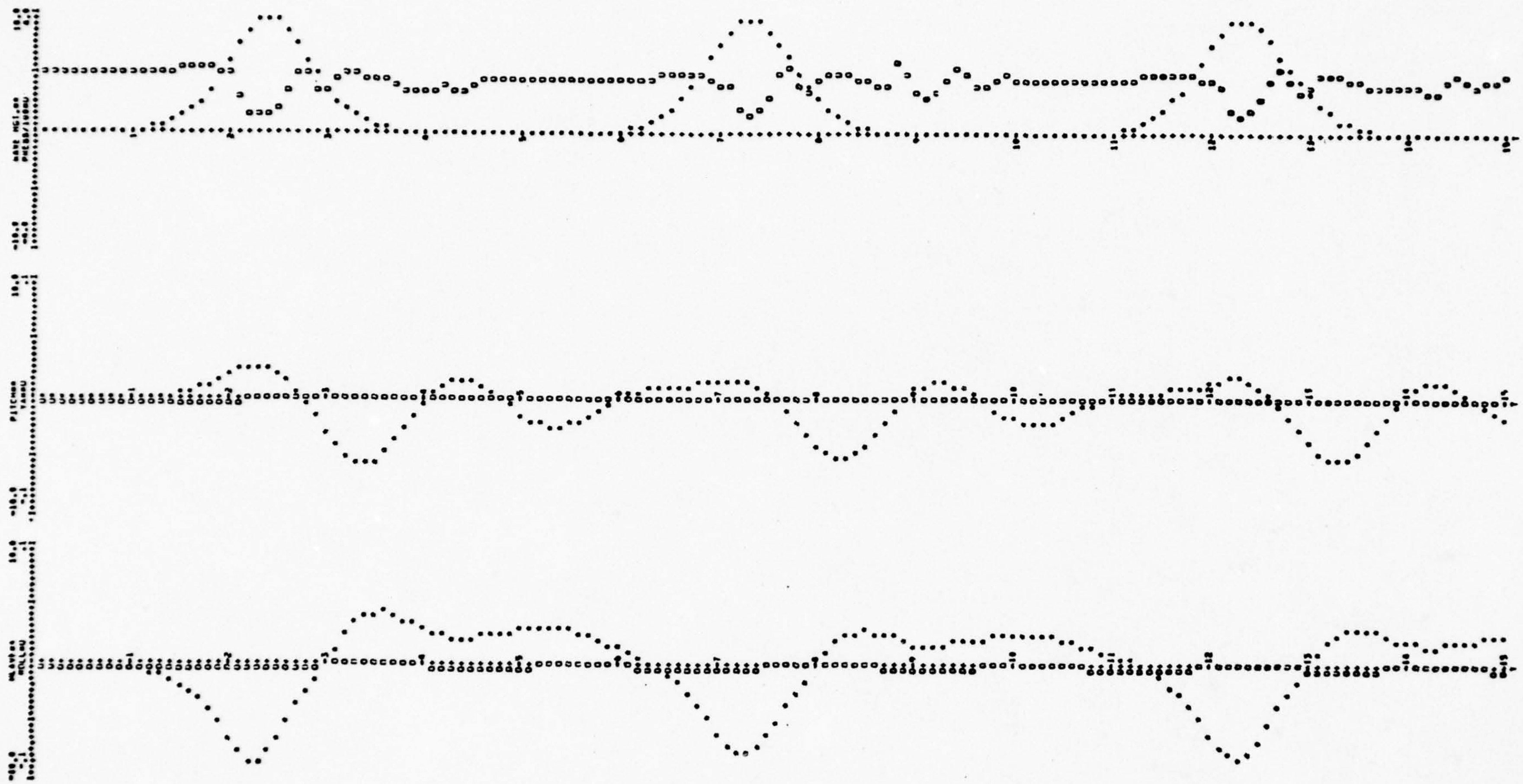

Figure 14 Craft Response in Shallow Water - water depth = 60 ft, wave period = 30 sec, wave height = 10 ft, craft speed = 50 knots, craft heading = 180 deg, $\frac{t}{T}$ = 2.25 sec

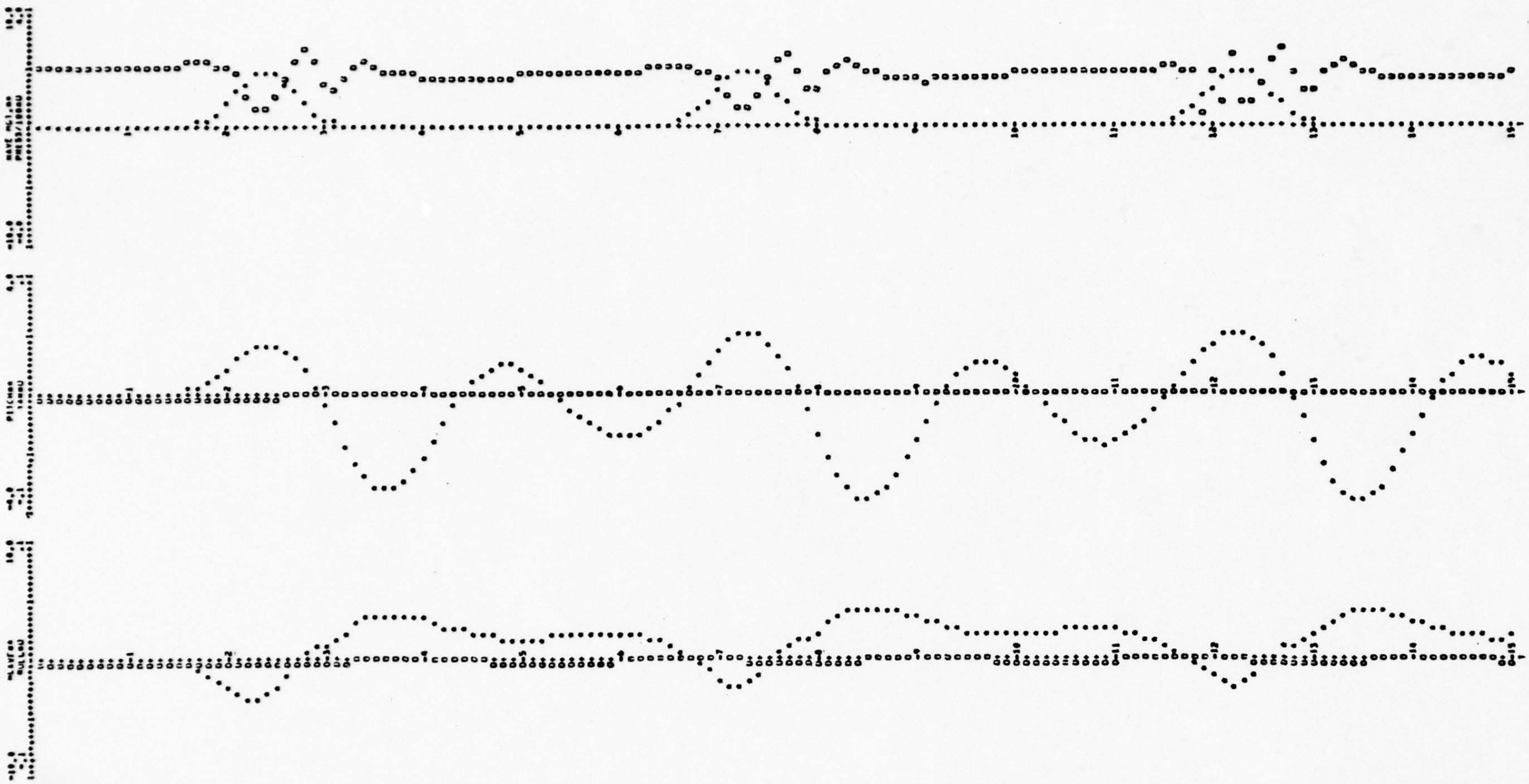

Figure 15 Craft Response in Shallow Water - water depth = 30 ft, wave period = 30 sec, wave height = 5 ft, craft speed = 50 knots, craft heading = 180 deg $\frac{t}{T}$ = 1.78 sec

The normal reaction of the craft on encountering the wave front is to increase its trim with a simultaneous decrease in immersion. This behavior is to be anticipated since the craft is impacting the wave. In accordance with this reaction the cushion pressure decreases due to increase leakage. After the wave crest, trim decreases and immersion increases.

In figure 16 it is apparent that large excursions in pitch and heave are occurring and furthermore these motions are diverging. This particular run condition however, has been taken at a ratio of wave length to cushion length of 2.18, which is very close to the wave pumping condition of 2. Therefore it is expected that severe conditions will arise, as seen in Table 3. The maximum heave and pitch are larger in relation to the wave amplitude than in all other cases. It is apparent that under this condition the craft is not likely to survive without evasive action.

6.3 Deep Water Explosion Wave Response

A deep water explosion wave environment was generated by considering the wave caused by a yield device of 1 kiloton. It was assumed that the stand-off distance of the craft from the center of the blast was 7,500 feet. A device having this yield and exploding at the upper critical depth would cause an initial water disturbance having an initial radius of 740 feet and initial water height of 55 feet. Using these conditions the craft response was calculated for a hovering situation at 0 degree heading, and at 50 knots for headings of 90°, (beam sea), 45° and 135°. The results of these runs are shown in figures 17 through 20.

From figure 17 it is seen that at this distance from the blast, the maximum wave height encountered is approximately 6 feet. The graph shows the arrival of the first wave group and the

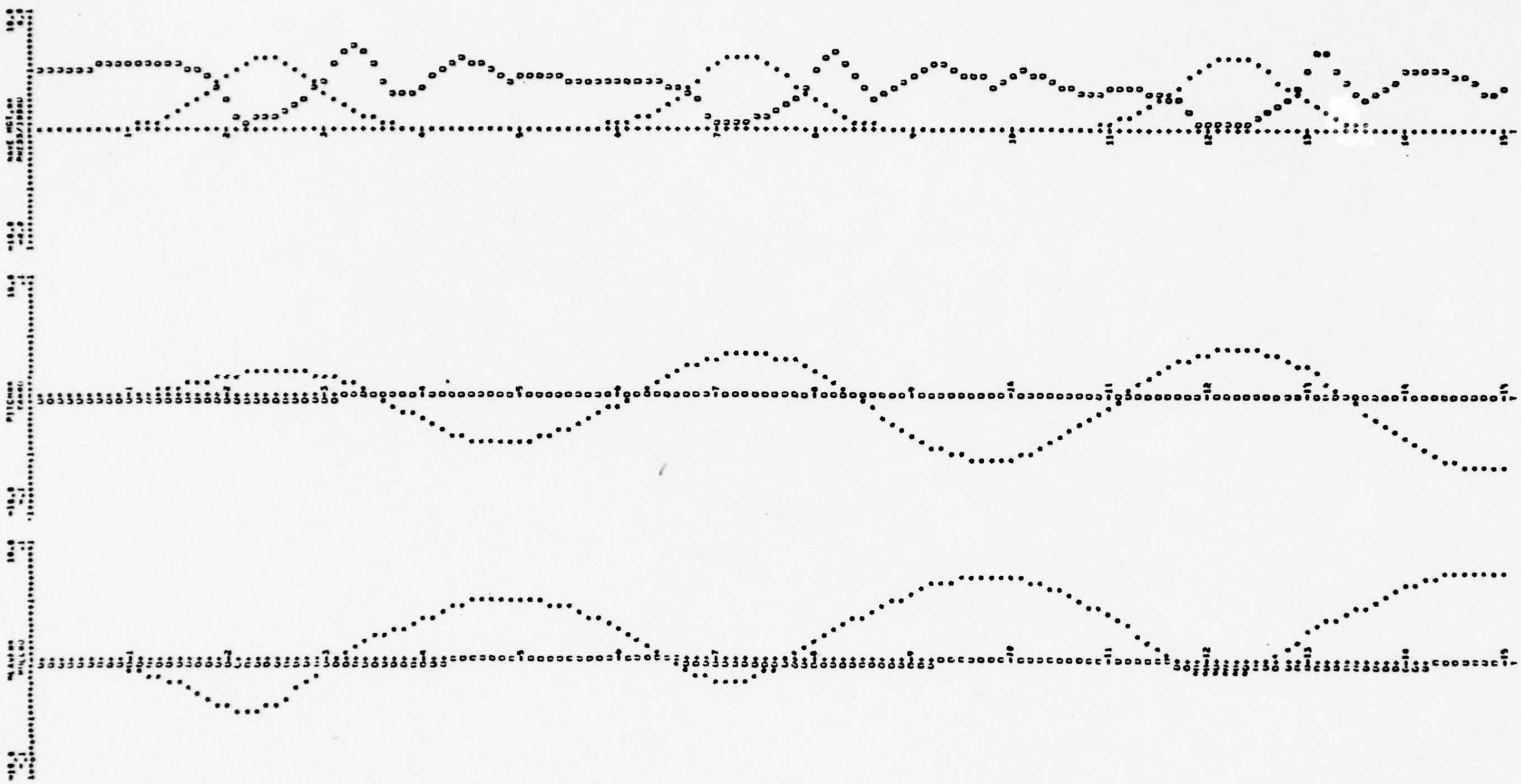

Figure 16 Craft Response in Shallow Water - water depth = 30 ft, wave period = 15 sec, wave height = 6.5 ft, craft speed = 50 knots, Craft heading = 180 deg, $\frac{t}{T}$ = 0.91 sec

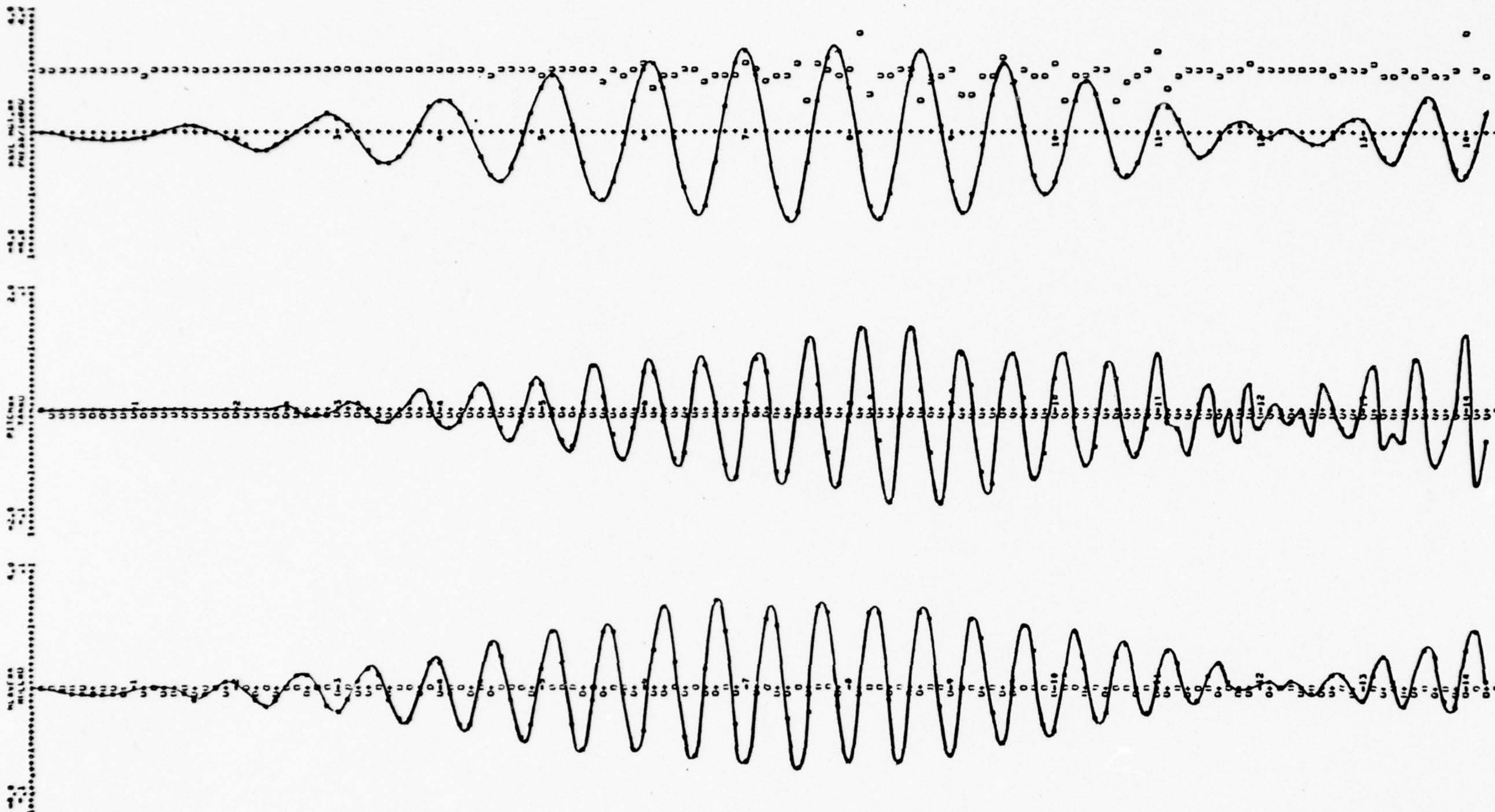

Figure 17 Craft Response to Explosion Waves in Deep Water - yield = 1 kt, stand-off distance = 7500 ft, craft speed = 0 (hovering), craft heading = 0 deg $\frac{t}{T}$ = 4.68 sec T_o = 80 sec

subsequent response of the craft. As seen all the variables are within normal excursions with a maximum pitch of -1.55° and heave of 2.85 feet. The wave envelop shown in this figure is typical of the explosion generated wave envelopes.

Should a blast occur off the beam of the craft when operating at 50 knots the results indicate that the craft will barely survive the waves. As seen in figure 18 large excursions in yaw, roll and heave are experienced. The maximum excursion in these variables are:

maximum heave = 4.85 feet
maximum roll = 8.98°
maximum yaw = -11.91°

The maximum pitch angle experienced is -1.52° which is quite nominal. It is apparent from this response that the craft is quite vulnerable to beam explosions.

Should the craft be operating at 50 knots and an explosion occur the question arises as to what evasive action it should take. As a preliminary maneuver it was assumed that a reaction time of 80 seconds is required for the craft to either alter its course to another heading or head up into the blast and kill its engines. We have seen that in this latter mode it can survive the present explosion. The question arises as to whether an alternative course heading is preferable. To investigate this possibility two headings of 45° and 135° were investigated.

Figure 19 shows the response of the craft to the waves environment on a heading of 45° assuming such a heading is achieved 80 seconds after the blast. As will be seen little if any motion occurs to the craft since the craft is heading away from the wave front and is apparently in small, long period waves ahead of the main group of waves. Provided sufficient clear sea is available the craft could outrun the wave until the waves

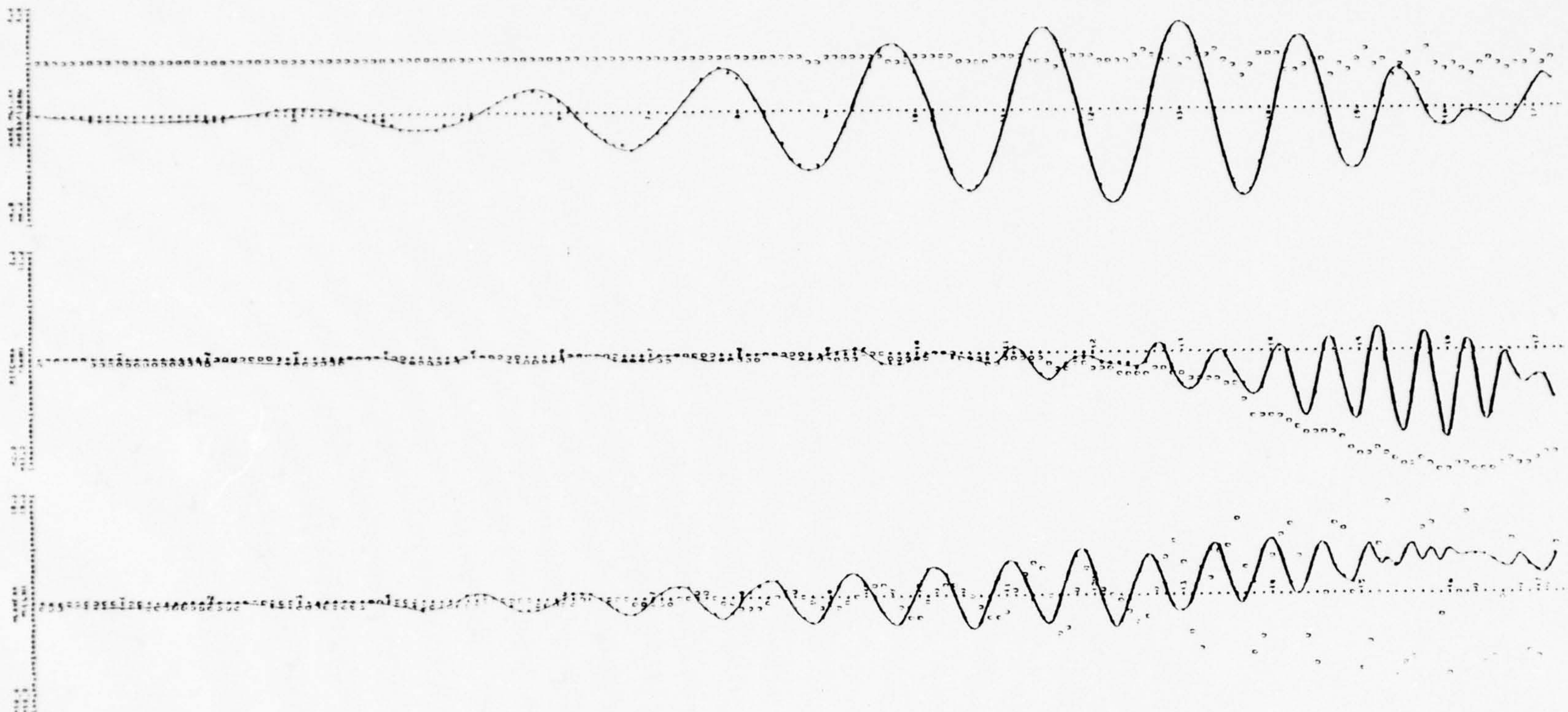

Figure 18 Craft Response to Explosion Waves in Deep Water - yield = 1 kt, stand-off distance = 7500 ft, craft speed = 50 knots, craft heading = 90°, $\frac{t}{T}$ = 2.34 sec, T_o = 80 sec

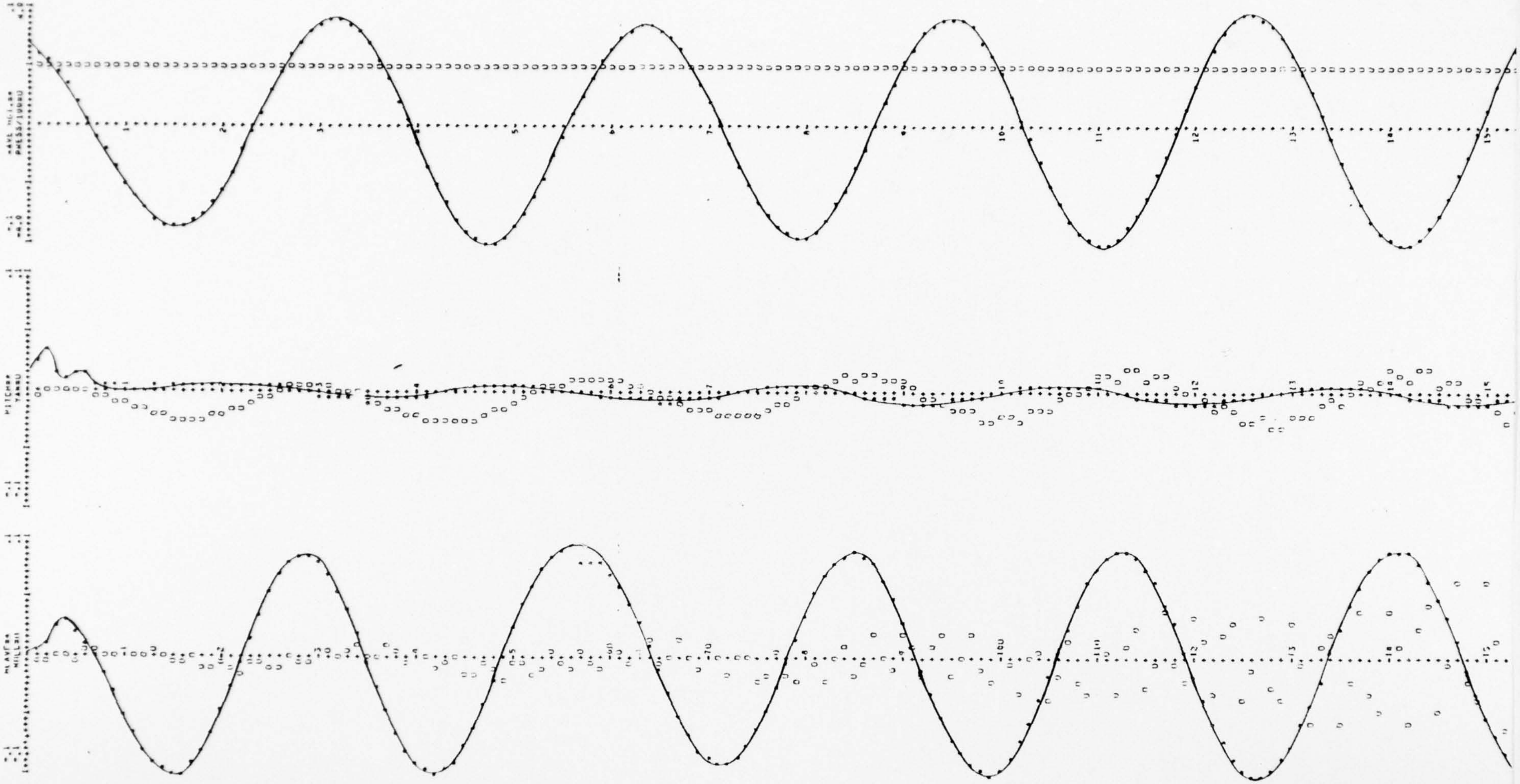

Figure 19 Craft Response to Explosion Waves in Deep Water - yield = 1 kt, stand-off distance = 7500 ft, craft speed = 50 knots, craft heading = 45°, $\frac{t}{T}$ = 3.83 sec, T_o = 80 sec

had decayed sufficiently to allow a change in heading. This situation would obviously be changed if the continental margin were reached, since in that case the waves would begin to experience bottom effects and become solitary waves.

Should the craft head into the blast on a 135° course, an unlikely situation, unless it was already on this course when the blast occurred the response is shown in figure 20. Here it will be seen that the motions are diverging and indeed, based on the present analysis, the craft will not survive. As will be seen the run was actually terminated before the motions become excessive. The maximum excursions of the craft at this point are:

maximum heave = 4.526
maximum pitch = 1.548
maximum roll = 2.325
maximum yaw = -0.331

It is apparent from this brief survey that dependent on the location of the blast relative to the craft and the available response time several possible scenarios exist for evasive action subsequent to a blast. This evasive action, however depends on a great many variables and will be the topic of further investigation during the next phase of the present program. It it clear however, that relatively moderate yields can cause an SES considerable difficulty if cognizance of the seriousness of the situation is not realized.

It should be reiterated at this point that the above analyses were performed without heave alleviation devices on the craft. The results should therefore be viewed in this light.

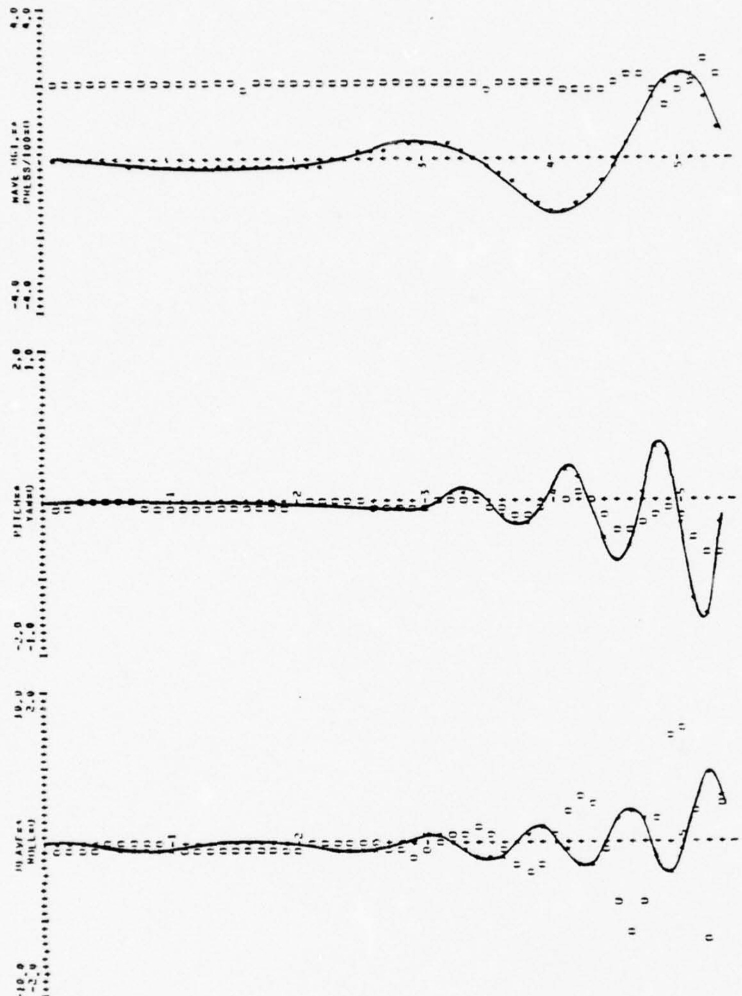

Figure 20 Craft Response to Explosion Waves in Deep Water - yield = 1 kt, stand-off distance = 7500 ft, craft speed = 50 knots, craft heading = 135°, $\frac{t}{T}$ = 1.69 sec, T_o = 80 sec

7. CONCLUSIONS

We have presented the preliminary results derived from modelling the response of a typical SES to an explosion type wave environment. This effort represents the status of the project at the end of its first phase and is by no means complete. Results obtained to date however, indicate that some consideration is needed to developing suitable tactical maneuvers for minimizing damage potential from explosion generated wave environments. It is further apparent that the unique high speed capability of these vehicles provides them with a great deal of versatility in generating evasive action.

It is presently planned in the next phase of the project to take the procedure further with the development of the computer code to enhance its versatility and to perform a parametric analysis on the various variables of the problem, in order to develop a meaningful procedure for action under possible threats of this nature. Such scenarios would be most valuable in future planning of the operational fleet.

8. REFERENCES

1. LeMéhauté, B., Hwang, L., Divoky, D., and Butler, H.L., "Explosion-generated Wave Environment in Shallow Water," Tetra Tech Report TC-116, 1967

2. Wang, S., "Ship Behavior in Explosion-Generated Wave Environment," Tetra Tech Report TC-130D, 1970
   Yang, I-M, "Theoretical and Experimental Study of Submarine Dynamics With Applications to Explosion Generated Waves," Tetra Tech Report TC-181, 1971
   Wang, S., Hwang, L., and Webb, L., "Study of Ship Vulnerability to Large Waves Raised by Nuclear Explosion," Tetra Tech Report TC-213, 1972

3. Wade, R.B., and Wang, S., "Some Aspects of Sidehull Hydrodynamics and Maneuvering in the Design of Surface Effect Ships," 11th Symposium of Naval Hydrodynamics, 1976.

4. Lamb, H., "Hydrodynamics," Sixth Edition, Dover, New York, 1932.

5. Chapman, R.B., "Spray Drag of Surface-Piercing Struts," NUC TP251, 1971

6. Yim, B., "On the Wave Resistance of Surface Effect Ships," J. Ship Res., Vol 15, No. 1, March 1971

7. Kajiura, K., "The Leading Waves of Tsunami," Bulletin of the Earthquake Research Institute, Vol. 41

8. Van Dorn, W.G., LeMéhauté, B. and Hwang, L.,"Handbook of Explosion-generated Water Waves," Vol. I, Tetra Tech Report No. TC-130, 1968

9. LeMéhauté, B.,"Theory of Explosion-generated Water Waves," Advances in Hydroscience, Vol. 7, Academic Press, New York, 1971

10. Waterways Experiment Station, "Effects of Explosions in Shallow Water," Technical Memorandum No. 2-406, 1955

11. Glasstone, S.,"The Effects of Nuclear Weapons," U.S. Atomic Energy Commission, 1962

12. Garcia, W.J.,"Water Waves Produced by Cratering Explosions in Shallow Water," Lawrence Radiation Laboratory, University of California, Livermore, California, 1970.

13. LeMéhauté, B., Divoky, D. and Lin, A.,"Shallow Water Waves: A Comparison of Theories and Experiments," 11th Conference of Coastal Engineering, 1968

14. Divoky, D., LeMéhauté, B. and Lin, A.,"Breaking Waves on a Gentle Slope," J.G.R., Vol. 75, No. 9, 1970

APPENDIX A

COMPUTER INPUT/OUTPUT FORMAT

Computer Input and Output Format

Input Format:

Card 1: Format (20A4)

1) TITLE - Heading card.

Card 2: Format (F10.0, 14I5)

1) DT - Number of intervals per wave period.
2) NSTEP - Number of integration steps.
3) NPRNT - 1
4) IP - Debug flag for component forces and moments, printed in main program.
   If IP = 0, debug not printed.
   If IP ≠ 0, debug is printed.
5) IFIN - Flag on inclusion of stabilizer.
   If IFIN = 0, do not include stabilizer.
   If IFIN ≠ 0, include stabilizer.
6) IPLOT - Flag on plotting.
   If IPLOT = 0, call PLOTT.
   If IPLOT = 1, call PLOTXY.
   If IPLOT = 2, call PLOTT and PLOTXY.
   If IPLOT > 2, do not plot.
7) IPT - Number of points to plot for PLOTT.
8) NJET - Number of jets for thrust vector control.
9) INT - Flag for printing cumulative integrals and geometrical variables.
   If INT = 0, do not print.
   If INT ≠ 0, print.
10) IBUG - Flag on debug for subroutine BUOY.
    If IBUG = 0, do not print debug.
    If IBUG ≠ 0, print debug.
11) IW - Flag on wave type.
    If IW = 1, sinusoidal wave.
    If IW = 2, solitary wave
    If IW = 3, explosion wave
12) IPR - Flag on debug for pressure subroutine
    If IPR = 0, do not print debug.
    If IPR ≠ 0, print debug.
13) ICO - Flag for generating new derivatives when draft changes by more than ICO feet.
    If ICO = 0, do not change derivatives.
    If ICO > 0, ICO equals the change in draft required to update derivatives.

Card 3: Format (8F10.0)

1) THT - Initial pitch angle of craft (deg).
2) PHI - Initial roll angle of craft (deg).
3) PSI - Initial yaw angle of craft (deg).
4) Z - Heave (set = 0).

Card 4: Format (8F10.0)

1) AA - Distance from transom to C.G. (ft).
2) BB - Half spacing of side walls (ft).
3) CC - Side wall immersion at C.G. (ft).
4) DD - Distance from keel of craft to C.G. (ft).
5) AM - Craft weight (tons).
6) DXDU - Added mass coefficient of side wall in axial flow.
7) AIX - Moment of inertia of craft about the x-axis (ton-ft-sec^2).
8) AIZ - Moment of inertia of craft about the z-axis (ton-ft-sec^2).
9) AIY - Moment of inertia of craft about the y-axis (ton-ft-sec^2).

Card 5: Format (8F10.0)

1) WL - Reference length of craft (ft).
2) SP - Approaching speed (knots).
3) RHO - Density of water (lb. sec^2/ft^4)
4) ANU - Kinematic viscosity of water (ft^2/sec).
5) CDLL - Drag coefficient, lateral force, lateral motion.
6) CDNN - Drag coefficient, normal force, normal motion.

Card 6: Format (8F10.0)

1) OMEGA - Dihedral angle of stabilizer (deg).
2) CR - Chord length of stabilizer at root (ft).
3) CT - Chord length of stabilizer at tip (ft).
4) S - Stabilizer span (ft).

Card 7: Format (8F10.0)

1) CCO - Side wall immersion at C.G. before turning (ft).
2) THTO - Pitch angle before turning (deg).
3) SPTURN - Assigned speed at turn if different from SP (knots).
4) DFTH - Control for differential thrust (set = 0).

Card 8: Format (8F10.0)

1) XARM - Longitudinal distance of water jet nozzle location from craft C.G. (ft).
2) ZARM - Vertical distance of water jet nozzle location below craft C.G. (ft).
3) BACE - Vertical location of the stabilizer attachment below the keel line (ft).

Card 9: Format (8F10.0)

1) YARM(I) - Transverse location of Ith water jet nozzle from craft centerline (ft) NJET values. Positive starboard side.

Card 10: Format (8F10.0)

1) DELJET(I) - Deflection angle of nozzle I (deg). NJET values. Positive toward port side.

Card 11: Format (8F10.0)

1) RMCP(I) - Engine power level delivered to nozzle I. NJET values.

Card 12: Format (8F10.0)

1) ALPHA(I) - Vertical tilt angle of nozzle I (deg). NJET values. Positive upward.

Card 13: Format (8F10.0)

1) DWET - Distance from keel to wet deck (ft).
2) WAMP - Wave amplitude (ft).
3) WPER - Wave period (sec.).
4) BETA - Heading angle (deg)
   BETA = 0°, following or overtaking waves.
   BETA = 180°, head waves.
5) WDEP - Water depth (ft).
6) XO - Distance from center of explosion to craft (ft).
7) RO - Crater radius (ft).
8) ETAO - Crater height (ft).
9) TO - Reference time with respect to time of detonation (sec).

Card 14: Format (16I5)

1) NST - Number of sections along craft from transom to bow.

Card 15: Format (8F10.0)

1) BUBL - Air cushion bubble length (ft).
2) BUBB - Air cushion bubble width (ft).
3) WALB - Maximum width of side wall (ft).
4) DEPTH - Depth of craft (ft).

Card 16: Format (8F10.0)

1) SLBOW - Length of planing bow seal (ft).
2) SLSTRN - Length of planing stern seal (ft).
3) THETA - Angle of planing seal (deg).

Card 17: Format (8F10.0)

1) DRISE(I) - Dead rise angle at station I (deg). NST values. I = 1 at transom, I = NST at bow.

Card 18: Format (8F10.0)

1) ENTRCE(I) - Average entrance angle at station I (deg). NST values.

Card 19: Format (8F10.0)

1) CHINE(I) - Height of chine above keel line at station I (ft).

Card 20: Format (8F10.0)

1) NSW(I) - Number of water lines used for defining offsets at station I.

Card 21: Format (8F10.0)

1) XSW(I) - Distance from transom to station I (ft). NST values.

Card 22: Format (8F10.0)

1) HSW(I) - Height of bottom profile above keel line at station I (ft). If profile below keel line HSW(I) is negative.

Card Group 23: Format (8F10.0)

1) D1(I,J) - Height of Jth waterline above keel at Ith station (ft). NSW(I) values of D1 for each I. All values are positive. D1(I,1) = 0.0. Refer to figure A.1.

D1 is input as follows:
Card 1 - D1(1,I), D1(1,2), ... D1(1, NSW(1)).
Card 2 - D1(2,1), D1(2,2), ... D1(2, NSW(2)).
Card NST - D1(NST,1), D1(NST,2), ... D1(NST,NSW(NST)).

Card Group 24: Format (8F10.0)

1) W1(I,J) - Horizontal offset of the starboard wall, right side of vertical reference plane, at Ith station and Jth waterline (ft). NSW(I) values of W1 for each I. All values are positive. W1(I,J) input similarly to D1(I,J). Refer to figure A.1.

Card Group 25: <u>Format</u> (8F10.0)

1) W2(I,J) - Horizontal offset of the port wall, left side of vertical reference plane, at Ith station and Jth waterline (ft). NSW(I) values of W2 for each I. All values are positive. W2(I,J) input similarly to D1(I,J). Refer to figure A.1.

The following nondimensional derivatives may be obtained by calculation or from model tests.

Card 26: <u>Format</u> (8F10.0)

1) DYV - y'_v
2) DYP - y'_p
3) DYR - y'_r
4) DYDV - $y'_{\dot{v}}$
5) DYDP - $y'_{\dot{p}}$
6) DYDR - $y'_{\dot{r}}$

Card 27: <u>Format</u> (8F10.0)

1) DKV - k'_v
2) DKP - k'_p
3) DKR - k'_r
4) DKDV - $k'_{\dot{v}}$
5) DKDP - $k'_{\dot{p}}$
6) DKDR - $k'_{\dot{r}}$

Card 28: <u>Format</u> (8F10.0)

1) DNV - n'_v
2) DNP - n'_p
3) DNR - n'_r
4) DNDV - $n'_{\dot{v}}$
5) DNDP - $n'_{\dot{p}}$
6) DNDR - $n'_{\dot{r}}$

If CC $\neq$ CCO a second set of nondimensional derivatives are read as cards 29, 30 and 31.

Card 29: Similar to card 26 for CC, THT case.
Card 30: Similar to card 27 for CC, THT case.
Card 31: Similar to card 28 for CC, THT case.

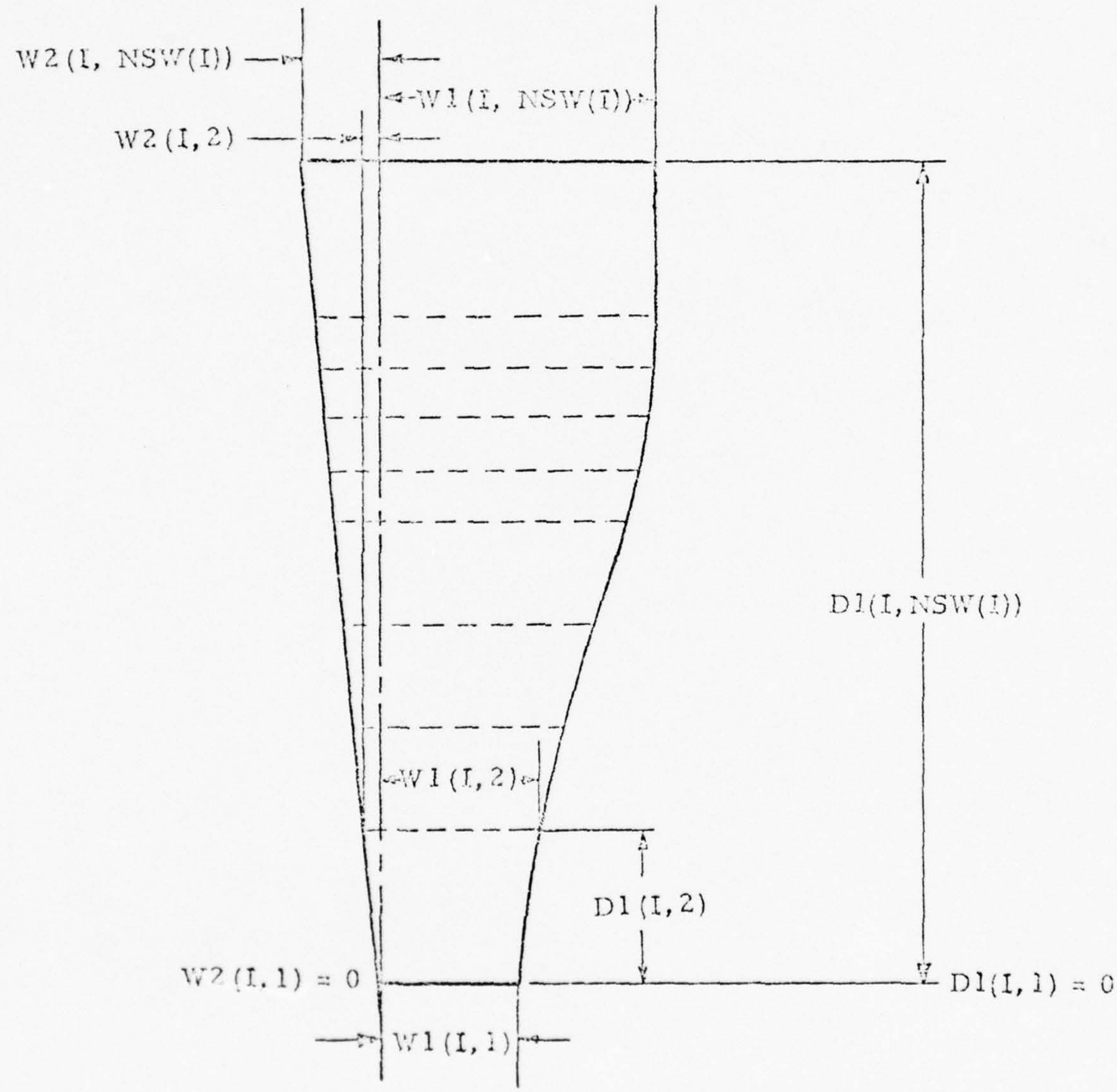

Figure A-1: D1, W1, W2 for Cross Section I.

Definition of Output

1. Input data are reproduced as they appear on data cards, with the exception of D1, W1, W2 which are not printed in the order they are read.

2. Any input data that are converted in the program are printed in new units.

   1) SP (ft/sec).
   2) AM (non-dimensional).
   3) AIX (non-dimensional).
   4) AIY (non-dimensional).
   5) AIZ (non-dimensional)
   6) FROUDE (non-dimensional) - Froude number

3. Craft attitude

   1) Draft (ft).
   2) Trim (deg).

4. Non-dimensional derivatives printed as read from input.

5. Stabilizer coefficients.

6. Coefficients for ship plus stabilizer.

7. Stability criterion for ship only.

8. Stability criterion for ship plus stabilizer.

9. Center of pressure of sidewall.

10. Non-dimensional cumulative integrals.

$$DI - \int_{p\&s} D\, dF$$

$$DFI - \int_{p\&s} DF\, dF$$

$$DF2I - \int_{p\&s} DF^2 dF$$

$$DF3I - \int_{p\&s} DF^3 dF$$

$$DCI - \int_{p\&s} DC\, dF$$

$$DC2I - \int_{p\&s} DC^2 dF$$

$$DC3I - \int_{p\&s} DC^3 dF$$

$$DCFI - \int_{p\&s} DCF\, dF$$

$$DCF2I - \int_{p\&s} DCF^2 dF$$

$$DC2FI - \int_{p\&s} DC^2 F\, dF$$

$$B3BI - BB^3 \int_{p\&s} B\, dF$$

where

p&s - Integration limits over both port and starboard sidewalls.

D - Draft at successive stations.

F - Distance from C.G. to successive stations.

C - Vertical moment arm, at successive stations, for submerged portions of craft (ft).

B - Beam at successive stations.

BB - Half spacing of side walls.

11. Non-dimensional Geometrical Variables as Function of Roll.

GI(I) - Integral of girder.
SI(I) - Integral of cross sectional area.
S1(I) - Cross sectional area at transom.
TDRAF(I) - Draft at transom.

If CC≠ CCO output from (3) to (11) will be printed for new craft attitude corresponding to CC and THT.

12. Craft characteristics.

13. Wave characteristics.

14. Table of output plus units:

1) T - Time (sec).
2) U - Craft speed (knots)
3) BETA - Sideslip angle (deg).
4) W - Heave rate (ft/sec).
5) X
6) Y   Location of craft (craft lengths).
7) Z - Heave (ft).
8) PHI - Roll angle (deg).
9) THETA - Pitch angle (deg).
10) PSI - Yaw angle (deg).
11) PC - Cushion pressure, gage pressure (psf).
12) QF - Fan flow (ft^3/sec)
13) QO - Leakage flow, difference from initial condition (ft^3/sec).
14) VOLDOT - Rate of cushion volume variation (ft^3/sec).
15) WD - Heave acceleration (G's).
16) WH - Wave elevation at C.G. of craft (ft).
17) VOL - Cushion volume (ft^3).

15. Legend for computer plots:

1) HEAVE - Heave (ft).
2) ROLL - Roll angle (deg).
3) PITCH - Pitch angle (deg).
4) YAW - Yaw angle (deg).
5) WAV HGT - Wave elevation at C.G. of craft (ft).
6) PRESS/100 - Cushion pressure divided by 100 (pst).

```
INPUT DATA


TEST SIDEWALL - EXPLOSION WAVE
DT,NSTEP,NPRNT,IP,IFIN,IPLOT,IPT,NJET,INT,IBUG,IW,IPR,ICO
   128.00  691     1     0     1     0  691     4     0    -0     3    -0     1
THT,PHI,PSI,Z
    -0.00       -0.00       -0.00       -0.00
AA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY
  130.000      44.000      2.000      24.000      2000.0       0.000     65000.0   300000.0   200000.0
WL,SP,RHO,ANU,COLL,CONN
  237.500      56.000      1.988   .000012817      1.300       1.000
OMEGA,CR,CT,S
    30.00       10.00       5.00       10.00
CCO,THTO,SPTURN,DFTH
     2.00        1.00      50.00        0.00
XARM,ZARM,BACE
   130.00        0.00       0.00
YARM(I)
    50.00      -50.00      38.00      -38.00
DELJET(I)
    -0.00       -0.00      -0.00       -0.00
RMCP(I)
     1.00        1.00       1.00        1.00
ALPHA(I)
    -0.00       -0.00      -0.00       -0.00
DWET,WAMP,WPER,BETA,WDEP,XO,RO,ETAO,TO
    18.00       10.00      30.00       45.00     2000.00     7500.00      740.00       55.00       80.00
CDIS,RHOWA,ATM,PHIO,PHII,THTB,THTS
    .70     .002378 2117.0075497.09 -121.25     30.00       60.00
NST
  12
BUBL,HUBB,WALB,DEPTH
   240.00       88.00       8.00       30.00
SLBOW,SLSTRN,THETA
    20.00       20.00      15.00
DRISE(I)
    85.00       85.00      85.00       79.00       60.00       49.00       44.00       43.00
    45.00       56.00      78.00       78.00
ENTRCE(I)
    -0.00       -0.00      -0.00       -0.00       -0.00       -0.00       -0.00       -0.00
     1.50        8.50      10.50        0.00
CHINE(I)
     5.00        5.00       5.00        5.00        5.00        5.00        5.00        5.00
     5.00        6.00       9.00        0.00
NSW
  4     4     4     4     4     4     4     4     3     3     3     1
XSW
     0.00       25.00      50.00       75.00      100.00      125.00      150.00      175.00
   200.00      225.00     237.50      250.00
HSW
    -0.00       -0.00      -0.00       -0.00       -0.00       -0.00       -0.00       -0.00
     0.00        0.00       0.00       20.00

    1  DL         0.000        5.000       10.000       20.000
       WL         7.000        7.500        8.000        8.000
       W2        -0.000       -0.000       -0.000       -0.000

    2  DL         0.000        5.000       10.000       20.000
       WL         7.000        7.500        8.000        8.000
       W2        -0.000       -0.000       -0.000       -0.000
```

3	DL	0.000	5.000	10.000	20.000
	WL	7.000	7.500	8.000	8.000
	W2	-0.000	-0.000	-0.000	-0.000
4	DL	0.000	5.000	10.000	20.000
	WL	6.500	7.500	8.000	8.000
	W2	-0.000	-0.000	-0.000	-0.000
5	DL	0.000	5.000	10.000	20.000
	WL	4.000	7.000	8.000	8.000
	W2	-0.000	-0.000	-0.000	-0.000
6	DL	0.000	5.000	10.000	20.000
	WL	2.000	6.500	8.000	8.000
	W2	-0.000	-0.000	-0.000	-0.000
7	DL	0.000	5.000	10.500	20.000
	WL	.700	6.000	8.000	8.000
	W2	-0.000	-0.000	-0.000	-0.000
8	DL	0.000	5.000	13.500	20.000
	WL	0.000	5.500	8.000	8.000
	W2	-0.000	-0.000	-0.000	-0.000
9	DL	0.000	5.000	20.000	
	WL	0.000	5.000	8.000	
	W2	-0.000	-0.000	-0.000	
10	DL	0.000	6.000	20.000	
	WL	0.000	4.000	6.500	
	W2	-0.000	-0.000	-0.000	
11	DL	0.000	9.000	20.000	
	WL	0.000	2.000	5.000	
	W2	-0.000	-0.000	-0.000	
12	DL	0.000			
	WL	0.000			
	W2	-0.000			

CONVERTED INPUT
SP,AM,AIX,AIY,AIZ,FROUDE
84.45 .1045E-01 .1939E-03 .5966E-03 .8949E-03 .9657

DRAFT= 2.00 TRIM= 1.00

NON DIMENSIONAL DERIVATIVES

```
DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW
 -.9364E-03  0.          .1517E-02  -.2772E-02  0.          -.2365E-03  0.          .2843E-03  -.9062E-03  0.
DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW
 0.          -.1633E-02  0.          0.          -.2984E-02  0.          -.4103E-03  0.          0.          -.1310E-02
DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW
 .4082E-05   0.          .1296E-03  -.2404E-03  0.          .2178E-05   0.          .2410E-04  -.7779E-04  0.
DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW
 0.          -.4337E-03  0.          0.          -.3235E-03  0.          -.1611E-03  0.          0.          -.4103E-03
DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
 .5510E-04   0.          -.5462E-03  .6111E-03  0.          .7378E-04   0.          -.1211E-03  .2843E-03  0.
```

STABILIZER COEFFICIENTS

```
FINYV=  -.4682E-02
FINYR=   .2489E-02
FINKV=   .8615E-04
FINKR=  -.4579E-04
FINNV=   .2489E-02
FINNR=  -.1323E-02
```

SHIP PLUS STABILIZER COEFFICIENTS

```
SFYV=  -.7454E-02
SFYR=   .4006E-02
SFKV=  -.1543E-03
SFKR=   .8377E-04
SFNV=   .3100E-02
SFNR=  -.1869E-02
```

STABILITY CRITERION FOR SHIP ONLY= .6973E-05
STABILITY CRITERION FOR SHIP PLUS FIN= .3391E-04
CENTER OF PRESSURE AT CENTER OF GRAVITY= 22.85

SEC	DI	DFI	DF2I	DF3I	DCI	DC2I	DC3I	DCFI	DCF2I	DC2FI	BSBI
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	.180E-02	-.893E-03	.449E-03	-.229E-03	.166E-03	.153E-04	.142E-05	-.825E-04	.415E-04	-.762E-05	.209E-0
3	.340E-02	-.152E-02	.701E-03	-.331E-03	.315E-03	.293E-04	.272E-05	-.141E-03	.649E-04	-.131E-04	.416E-0
4	.481E-02	-.193E-02	.821E-03	-.368E-03	.448E-03	.418E-04	.390E-05	-.179E-03	.763E-04	-.167E-04	.620E-0
5	.602E-02	-.215E-02	.866E-03	-.377E-03	.564E-03	.528E-04	.494E-05	-.201E-03	.805E-04	-.187E-04	.797E-0
6	.704E-02	-.223E-02	.875E-03	-.378E-03	.662E-03	.622E-04	.584E-05	-.208E-03	.813E-04	-.194E-04	.930E-0
7	.787E-02	-.221E-02	.877E-03	-.378E-03	.742E-03	.699E-04	.659E-05	-.206E-03	.816E-04	-.192E-04	.102E-0
8	.851E-02	-.213E-02	.890E-03	-.376E-03	.803E-03	.759E-04	.717E-05	-.198E-03	.826E-04	-.185E-04	.107E-0
9	.895E-02	-.203E-02	.914E-03	-.370E-03	.847E-03	.801E-04	.759E-05	-.188E-03	.852E-04	-.175E-04	.110E-0
10	.920E-02	-.194E-02	.941E-03	-.360E-03	.871E-03	.826E-04	.783E-05	-.180E-03	.879E-04	-.167E-04	.112E-0
11	.925E-02	-.192E-02	.950E-03	-.357E-03	.876E-03	.831E-04	.788E-05	-.178E-03	.888E-04	-.165E-04	.112E-0
12	.926E-02	-.192E-02	.953E-03	-.355E-03	.878E-03	.832E-04	.790E-05	-.177E-03	.891E-04	-.164E-04	.112E-0

GEOMETRICAL VARIABLES

ROLL(DEG)	GT	SI	S1	IDRAF
2.000	.4822E-01	.3502E-03	.7502E-03	.2444E-01
1.000	.4043E-01	.2640E-03	.6476E-03	.2121E-01
0.000	.3344E-01	.2040E-03	.5459E-03	.1797E-01
-1.000	.2420E-01	.1279E-03	.4009E-03	.1339E-01
-2.000	.1956E-01	.8104E-04	.3018E-03	.1007E-01

APPENDIX B

COMPUTER LISTING

```
      PROGRAM SESWAVE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1
     *,TAPE2)
      DIMENSION Y(12),YP(12)
      DIMENSION RP(700),VP(700),PHID(700),XP(700),YYP(700),ACC(700)
     *,BETARD(700),UP(700),THTD(700),ZP(700),WP(700),WD(700)
     *,PSID(700),WAV(700),PCP(700)
      COMMON /A/ PDOT,QDOT,RDOT,PHIDOT,THTDOT,PSIDOT,UDOT,VDOT,WDOT,
     *XDOT,YDOT,ZDOT
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      COMMON /DERV/ NK,DELTA,FX,FY,FK,FN,XUDELU,DRAGY,DRAGN,
     *DELTAY,DELTAN,DRACK,BETAR,DFTH,DELTAX,DELTAK,DFTHI,THRATE
     *,DELP,DELS,RPM,IFOIL,IFIN
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /PRNT/ DT,NSTEP,NPRNT,IP
      COMMON /TEMP/SX,SY,SK,SN,WAVEDG,AERODG,HYDROF,SPRYDG,SEALDG,
     *SKINDG,FINDG
      COMMON /TEMP1/ THIGH,TLOW,SHIPDG,TOTLDG,TX
      COMMON /THRST/ TCON1,TCON2,TCON3,IDRAG,CCO,THIO
      COMMON /U/ GI(25),SI(25),S1(25),PHO(25),IDRAF(25)
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
      COMMON /IVCC/ XARM,ZARM,BACE,YARM(4),DELJET(4),RMCP(4),NJET
     *,ALPHA(4)
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      COMMON /FLOW/ PC,QF,QU,VDOTP,AOP,AI
      COMMON /VOLM/ VOLP
      COMMON /TUVW/ PWM,PWZ,PMC,PZC,PSLZ,PSLM
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA,IW,WDEP,OFFSET
     *,WLG,ICO,XO,RO,ETAO,TO
      COMMON /ASDFG/ CCX

      SINH(E)=(EXP(E)-EXP(-E))/2.
      SECH(ARG)=2./(EXP(ARG)+EXP(-ARG))
      DATA C00,C01,C02,C03,C04/11.53924656,-52.76716255,107.1876292,
     *-100.9056818,35.23071874/
C
C     CALL INPUT
C
      LTAPE=1
      CALL INPT(LTAPE)
C
C     INITIALIZATION
C
      DFTHI=0.0
      DELTAX=0.0
      DELTAY=0.0
      DELTAZ=0.
      DELTAK=0.0
      DELTAM=0.
      DELTAN=0.0
      SHIPDG=0.
      TOTLDG=0.
      T=0.0
```

```
      U=U0
      INDX=0
      COEF=0.5*RHO*WL**2*SP**2
      NE=12
      Y(1)=U
      Y(2)=V
      Y(3)=W
      Y(4)=P
      Y(5)=Q
      Y(6)=R
      Y(7)=X
      Y(8)=YY
      Y(9)=Z
      Y(10)=PHI
      Y(11)=THT
      Y(12)=PSI
C
C     CALCULATE WEIGHT OF CRAFT AT INITIAL TRIM WITH NO WAVE
C
      INWGT=0
      CALL SEAWAV (WX,WY,WZ,WK,WM,WN,VOL,AO,Y,T)
      BUOYAN=-WZ
      WMO=WM
      WXO=WX
      INWGT=1
      CALL RUNGS(T,DT,NE,Y,YP,INDX)
      KNT=1
      TP=T*WL/SP
      UP(KNT)=U*SP/1.689
      VP(KNT)=-ATAN(V/U)/DTR
      WP(KNT)=W*SP
      WD(KNT)=WDOT
      PP=P
      QP=Q*SP/WL/DTR
      RP(KNT)=R*SP/WL/DTR
      XP(KNT)=X
      YYP(KNT)=YY
      ZP(KNT)=Z*WL
      PHID(KNT)=PHI/DTR
      THTD(KNT)=THT/DTR
      PSID(KNT)=PSI/DTR
      WAV(KNT)=0.
      ACC(KNT)=FROUDE**2*(R*U+VDOT)
      RADIUS=0.0
      IF(R.NE.0.0) RADIUS=U/R*WL
      BETARD(KNT)=BETAR/DTR
      TXP=TX*COEF
      TDRG=TOTLDG*COEF
C
C     INTEGRATION BY RUNGS
C
 1000 INC=0
      PAM=AM*G/2240.*(0.5*RHO*WL**3)
      PBB=2.*BB
      PTHTO=THTO/DTR
      PSP=SP/1.689
      PBETA=BETA/DTR
      CRAFTL=XSW(NST)*WL
      WRITE(6,300) PAM,  CRAFTL,PBB,PTHTO,CC,PSP
  300 FORMAT(1H1,21HCRAFT CHARACTERISTICS/5X,7HWEIGHT=,F6.0,5H TONS/
```

```
     *5X,13HCRAFT LENGTH=  ,F6.1,4H FT./5X,14HCUSHION WIDTH=,F6.1,4H FT.
     */5X,13HINITIAL TRIM=,F6.2,5H DEG./5X,14HINITIAL DRAFT=,F7.3,4H FT.
     */5X,14HINITIAL SPEED=,F5.0,6H KNOTS)
      IF(IW.LT.3) WRITE(6,301) PBETA,WAMP,WPER,WLG,CEL,CAY
  301 FORMAT(//21H WAVE CHARACTERISTICS/5X,8HHEADING=,F5.0,5H DEG./
     *5X,7HHEIGHT=,F5.1,4H FT./5X,7HPERIOD=,F5.1,5H SEC.
     */5X,7HLENGTH=,F6.1,4H FT./5X,9HCELERITY=,F6.1,7H FT/SEC
     */5X,8HWAV NO.=,F7.4)
      IF(IW.EQ.3) WRITE(6,302)           PBETA,WDEP,RO,ETAU,XO,TO
  302 FORMAT(//21H WAVE CHARACTERISTICS/5X,8HHEADING=,F5.0,5H DEG.
     */5X,5HWDEP=,F6.1,4H FT./5X,3HRO=,F7.1,4H FT.
     */5X,5HETAO=,F6.1,4H FT./5X,3HXO=,F8.1,4H FT.
     */5X,3HTO=,F6.1,5H SEC.)
      WRITE(6,220)
  220 FORMAT(1H1,5X,1HT,6X,1HU,3X,4HBETA,6X,1HW,6X,1HX,6X,1HY,7X,1HZ
     *,5X,3HPHI,3X,5HTHETA,5X,3HPSI,6X,2HPC,6X,2HQF,6X,2HQO,2X,6HVOLDOT,
     *5X,2HWD,5X,2HWH,7X,3HVOL)                                         C
      WRITE(6,222)
  222 FORMAT(3X,4HSECS,2X,5HKNOTS,4X,3HDEG,1X,6HFT/SEC,4X,3H/LC,4X,3H/LC
     *,6X,2HFT,5X,3HDEG,5X,3HDEG,5X,3HDEG,5X,3HPSF,1X,7HFT3/SEC,1X,
     *7HFT3/SEC,1X,7HFT3/SEC,4X,3HFT2,5X,2HFT,7X,3HFT3/)
      IF(IP.NE.0) WRITE(6,221)
  221 FORMAT(17X,2HSX,9X,2HSY,9X,2HSN,5X,6HXUDELU,6X,5HDRAGY,
     *6X,5HDRAGN,5X,6HDELTAY,5X,6HDELTAN,6X,5HTHIGH,7X,4HTLOW,5X,
     *   6HTOTLDG//)
      WRITE(6,200) TP,UP(KNT),VP(KNT),WP(KNT),XP(KNT),YYP(KNT),ZP(KNT),
     *PHID(KNT),THTD(KNT),PSID(KNT),PC,QF,QO,VDOTP,AOP,WAV(KNT)
      IF(IP.NE.0) WRITE(6,208) SX,SY,SN,XUDELU,DRAGY,DRAGN,DELTAY,DELTAN
     *    ,THIGH,TLOW,TOTLDG
     *,WAVEDG,AERODG,HYDROF,SPRYDG,SEALDG,SKINDG,FINDG
      INTRY=0
      CCX=CC
      DO 2 I=1,NSTEP
      IF(INTRY.EQ.1.AND. ICO.NE.0) CALL SECDER(LTAPE)
      INTRY=0
      INC=INC+1
      CALL RUNGS(T,DT,NE,Y,YP,INDX)
      U=Y(1)
      V=Y(2)
      W=Y(3)
      P=Y(4)
      Q=Y(5)
      R=Y(6)
      X=Y(7)
      YY=Y(8)
      Z=Y(9)
      PHI=Y(10)
      THT=Y(11)
      PSI=Y(12)
      IF(INC.NE.NPRNT) GO TO 2
      KNT=KNT+1
      TP=T*WL/SP
      UP(KNT)=U*SP/1.689
      VP(KNT)=-ATAN(V/U)/DTR
      WP(KNT)=W*SP
      WD(KNT)=WDOT*SP**2/WL/G
      PCP(KNT)=PC
      PP=P
      QP=Q*SP/WL/DTR
      RP(KNT)=R*SP/WL/DTR
```

```
      XP(KNT)=X
      YYP(KNT)=YY
      ZP(KNT)=Z*WL
      PHID(KNT)=PHI/DTR
      THTD(KNT)=THT/DTR
      PSID(KNT)=PSI/DTR
      CT=CEL*TP
      UT=(Y(7)*COS(BETA)+Y(8)*SIN(BETA))*WL
      GO TO (10,11,12),IW
   10 WAV(KNT)=-(WAMP*SIN(CAY*(UT-CT)))
      GO TO 13
   11 IT=ABS(UT-CT)/WLG
      A1=CAY*(UT-CT+OFFSET+IT*WLG)
      WAV(KNT)=WAMP*SECH(A1)**2
      GO TO 13
   12 H=WDEP
      TW=TP+TO
      S=UT+XO
      RF=S/TW/SQRT(G*H)
      IF(RF.GE..3) GO TO 4
      HK=1./(4.*RF**2)
      GO TO 5
    4 RF2=RF*RF
      RF3=RF2*RF
      RF4=RF3*RF
      HK=C04*RF4+C03*RF3+C02*RF2+C01*RF+C00
    5 CAY=HK/H
      OMEGA=CAY*SQRT(G*TANH(HK)/CAY)
      CEL=OMEGA/CAY
      CT=CEL*TW
      HK2=2.*HK
      SHK2=SINH(HK2)
      ARG=HK2/SHK2
      ARG1=1.+ARG
      ARG2=-ARG1/(ARG*(1.-HK2/TANH(HK2))+0.5*ARG1**2-ARG1)
      ROK=CAY*RO
      CALL BESSEL(3,ROK,BJ3)
      ARG4=CAY*(XO-CT+UT)
      WAV(KNT)=(ETAO*RO/S)*SQRT(ARG2)*BJ3*COS(ARG4)
   13 CONTINUE
      ACC(KNT)=FROUDE**2*(R*U+VDOT)
      RADIUS=0.0
      BETARD(KNT)=BETAR/DTR
      IF(R.NE.0.0) RADIUS=U/R*WL
      TXP=TX*COEF
      TDRG=TOTLDG*COEF
      PMT=PWM+PMC+PSLM
      PG=PC-2117.
      WRITE(6,209) TP,UP(KNT),VP(KNT),WP(KNT),XP(KNT),YYP(KNT),ZP(KNT),
     *PHID(KNT),THTD(KNT),PSID(KNT),PG,QF,QO,VDOTP,WD(KNT),WAV(KNT),AOP    C
      IF(IP.NE.0) WRITE(6,208) SX,SY,SN,XUDELU,DRAGY,DRAGN,DELTAY,DELTAN
     *     ,THIGH,TLOW,TOTLDG
     *,WAVLDG,AERODG,HYDROF,SPRYDG,SEALDG,SKINDG,FINDG
      IF(ICO.EQ.0) GO TO 15
      ZTEST=ZP(KNT)+WAV(KNT)
      ZTST=ABS(ZTEST+CC-CCX)
      IF(ZTST.LT.ICO) GO TO 15
      INTRY=1
      CCX=CC +ZTEST
   15 CONTINUE
```

```
      INC=0
    2 CONTINUE
      PCP(1)=0.
      DO 843 IJK=2,KNT
  843 PCP(IJK)=(PCP(IJK)-2117.)/100.
      KN8=0
      DO 767 IKQ=1,KNT,4
      KN8=KN8+1
      ZP(KN8)=ZP(IKQ)
      THTD(KN8)=THTD(IKQ)
      PHID(KN8)=PHID(IKQ)
      PSID(KN8)=PSID(IKQ)
      WAV(KN8)=WAV(IKQ)
  767 PCP(KN8)=PCP(IKQ)
      IPT=KN8
      IF(IPLOT.GT.2) CALL EXIT
      IF(IPLOT.EQ.0) CALL PLOTT(ZP,THTD,WAV,PHID,PSID,PCP,IPT,NC,NG)
      IF(IPLOT.EQ.1) CALL PLOTXY(XP,YYP,KNT)
      IF(IPLOT.EQ.2) CALL PLOTT(ZP,THTD,WAV,PHID,PSID,PCP,IPT,NC,NG)
      IF(IPLOT.EQ.2) CALL PLOTXY(XP,YYP,KNT)
  200 FORMAT(6F7.2,4F8.3,4F8.0,F7.3,F7.2,F10.0)                          C
  208 FORMAT(8X,11E11.3//)
      STOP
      END
vv
```

```
      SUBROUTINE INPT(L)
      DIMENSION TITLE(20)
      COMMON /A/ PDOT,QDOT,RDOT,PHIDOT,THTDOT,PSIDOT,UDOT,VDOT,WDOT,
     *XDOT,YDOT,ZDOT
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /DERV/ NK,DELTA,FX,FY,FK,FN,XUDELU,DRAGY,DRAGN,
     *DELTAY,DELTAN,DRACK,BETAR,DFTH,DELTAX,DELTAK,DFTHI,THRATE
     *,DELP,DELS,RPM,IFOIL,IFIN
      COMMON /FCOFF/ FYNCL,FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
      COMMON /FOYL/ C,ALFA,GAMA,XF
      COMMON /GEOMM/NSW(25),W1(25,25),W2(25,25),D1(25,25)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CONN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /PRNT/ DT,NSTEP,NPRNT,IP
      COMMON /PRES/ CDIS,RHOWA,PHIO,PHI1,ATM,PMAX,AC,DEM,IPR
      COMMON /TEMP/ SX,SY,SK,SN
      COMMON /TEMP1/ THIGH,TLOW,SHTPDG,TOTLOG
      COMMON /THRST/ TCON1,TCON2,TCON3,IDRAG,CCO,THTO
      COMMON /U/ GI(25),SI(25),SI(25),PHO(25),TDRAF(25)
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
      COMMON /INDER/ CR,CT,S,OMEGA
      COMMON /TVCC/ XARM,ZARM,BACE,YARM(4),DELJET(4),RMCP(4),NJET
     *,ALPHA(4)
      COMMON /ABC/ DRAFT(25),WEIGHT,BUBB,BUBL,WALB,SLBOW,SLSTRN,THETA,
     *DEPTH,SPRAYL
      COMMON /CDE/ DRISE(23),ENTRCE(23),CHINE(23),HSPRAY(23)
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      COMMON /WAV/ DWFT,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA,IW,WDEP,OFFSET
     *,WLG,ICO,XO,RO,ETAO,TO
      COMMON /PSEAL/ THTB,THTS
      COMMON /ASDFG/ CCX
C
C     DEFINITION OF INPUT FLAGS
C
C     NSTEP=NO. OF TIME STEPS TO EXECUTE
C     NPRNT=PRINTING INCREMENT
C     IP.NE.0- PRINT DEBUG
C     IFIN.NE.0-INCLUDE FIN
C     IPLOT---------FLAG ON PLOTTING
C                   IF IPLOT =0,PLOT PLOTT
C                   IF IPLOT =1 PLOT PLOTXY
C                   IF IPLOT =2 PLOT PLOTT AND PLOTXY
C                   IF IPLOT GT 2 DONT PLOT
C     IPT-----------NUMBER OF STEPS TO PLOT PLOTT
C     NJET----------NUMBER OF JETS FOR THRUST VECTOR CONTROL
C     INT-----------PRINT FLAG FOR CUMULATIVE INTEGRALS AND GEOMETRICAL VARIABLES
C                   IF INT=0, DONT PRINT
C                   IF INT.NE.0, PRINT
C     IW------------FLAG FOR WAVE TYPE
C                   IF IW=1, SINUSOIDAL WAVE
C                   IF IW=2, SOLITARY WAVE
C                   IF IW=3, EXPLOSION WAVE
C     ICO-----------FLAG FOR GENERATING NEW DERIVATIVES WHEN DRAFT
```

```
C                 CHANGES MORE THAN ICO FEET
C                 IF ICO=0, DONT CHANGE DERIVATIVES
C                 IF ICO.NE.0, CHANGE IN DRAFT REQUIRED TO CHANGE DERIVATIVES
C
      IF(L.EQ.2) GO TO 1000
C
C     READ AND WRITE INPUT
C
      READ(5,103) (TITLE(I),I=1,20)
      READ(5,101) DT,NSTEP,NPRNT,IP,IFIN,IPLOT,IPT,NJET,INT,IBUG,IW,IPR
     *,ICO
      READ(5,100) THT,PHI,PSI,Z
      READ(5,100) AA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY
      READ(5,100) WL,SP,RHO,ANU,CDLL,CDNN
      READ(5,100) OMEGA,CR,CT,S
      READ(5,100) CCO,THTO,SPTURN,DFTH
      READ(5,100) XARM,ZARM,BACE
      READ(5,100)(YARM(I),I=1,NJET)
      READ(5,100) (DELJET(I),I=1,NJET)
      READ(5,100) (RMCP(I),I=1,NJET)
      READ(5,100) (ALPHA(I),I=1,NJET)
      WRITE(6,200)
      WRITE(6,201) (TITLE(I),I=1,20)
      WRITE(6,202)DT,NSTEP,NPRNT,IP,IFIN,IPLOT,IPT,NJET,INT,IBUG,IW,IPR
     *,ICO
      WRITE(6,203) THT,PHI,PSI,Z
      WRITE(6,204)AA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY
      WRITE(6,205)WL,SP,RHO,ANU,CDLL,CDNN
      WRITE(6,207) OMEGA,CR,CT,S
      WRITE(6,208)CCO,THTO,SPTURN,DFTH
      WRITE(6,210) XARM,ZARM,BACE
      WRITE(6,211)
      WRITE(6,109) (YARM(I),I=1,NJET)
      WRITE(6,212)
      WRITE(6,109) (DELJET(I),I=1,NJET)
      WRITE(6,213)
      WRITE(6,109) (RMCP(I),I=1,NJET)
      WRITE(6,214)
      WRITE(6,109) (ALPHA(I),I=1,NJET)
C
C     READ AND WRITE INPUT FOR WAVE
C
      READ(5,100) DWET,WAMP,WPER,BETA,WDEP,XO,RO,ETAO,TO
      WRITE(6,241) DWET,WAMP,WPER,BETA,WDEP,XO,RO,ETAO,TO
C
C     READ AND WRITE INPUT FOR PRESSURE
C
      READ(5,100) CDIS,RHOWA,ATM,PHIO,PHI1,THTB,THTS
      WRITE(6,242)CDIS,RHOWA,ATM,PHIO,PHI1,THTB,THTS
C
C     READ AND WRITE INPUT FOR SPRAY
C
      READ(5,102) NST
      READ(5,100)       BUBL,BUBB,WALB,DEPTH
      READ(5,100) SLBOW,SLSTRN,THETA
      READ(5,100) (DRISE(I),I=1,NST)
      READ(5,100) (ENTRCE(I),I=1,NST)
      READ(5,100) (CHINE(I),I=1,NST)
      READ(5,102)      (NSW(I),I=1,NST)
      READ(5,100) (XSW(I),I=1,NST)
```

```
      READ(5,100) (HSW(I),I=1,NST)
      DO51 I=1,NST
      NVS=NSW(I)
   51 READ(5,100) (D1(I,J),J=1,NVS)                                     C
      DO52 I=1,NST
      NVS=NSW(I)
   52 READ(5,100) (W1(I,J),J=1,NVS)                                     C
      DO53 I=1,NST
      NVS=NSW(I)
   53 READ(5,100) (W2(I,J),J=1,NVS)                                     C
      WRITE(6,215) NST
      WRITE(6,216)       BUBL,BUBB,WALB,DEPTH
      WRITE(6,217)SLBOW,SLSTRN,THETA
      WRITE(6,218)
      WRITE(6,109)(DRISE(I),I=1,NST)
      WRITE(6,219)
      WRITE(6,109)(ENTRCE(I),I=1,NST)
      WRITE(6,220)
      WRITE(6,109)(CHINE(I),I=1,NST)
      WRITE(6,221)
      WRITE(6,102) (NSW(I),I=1,NST)
      WRITE(6,222)
      WRITE(6,109) (XSW(I),I=1,NST)
      WRITE(6,223)
      WRITE(6,109) (HSW(I),I=1,NST)
      DO54 I=1,NST
      NVS=NSW(I)
      WRITE(6,224)(I,(D1(I,J),J=1,NVS))
      WRITE(6,225) (W1(I,J),J=1,NVS)
      WRITE(6,226) (W2(I,J),J=1,NVS)
   54 CONTINUE
C     CONSTANTS
C
      NC=20
      NG=6
      G=32.2
      PI=3.1415927
      DTR=PI/180.
      P=Q=R=V=W=X=YY=0.
      U0=1.
      U=U0
      WEIGHT=AM*2240.
C
C     CONVERT TO RADIANS
C
      THT=THT*DTR
      PHI=PHI*DTR
      PSI=PSI*DTR
      OMEGA=OMEGA*DTR
      THTO=THTO*DTR
      BETA=BETA*DTR
      THTB=THTB*DTR
      THTS=THTS*DTR
C
C     CONVERT
C
      AIX=AIX*2240.
      AIY=AIY*2240.
      AIZ=AIZ*2240.
      AM=AM*2240./G
```

```
      SP=SP*1.689
      SPTURN=SPTURN*1.689
      FROUDE=SP/SQRT(G*WL)
C
C     CALCULATE CAY,CEL,F FOR SUBROUTINE SWAVE
C
      GO TO (41,42,43),IW
   41 CAY=4.*PI**2/(G*WPER**2)
      CEL=0.5*G*WPER/PI
      WLG=0.5*G*WPER**2/PI
      GO TO 44
   42 CAY=0.866*SQRT(WAMP/WDEP)/WDEP
      CEL=0.5*SQRT(G*WDEP)*(2.+WAMP/WDEP)
      WLG=CEL*WPER
      GO TO 44
   43 CAY=4.*PI**2/(G*30.0**2)
      CEL=0.5*G*30.0/PI
      WLG=0.5*G*30.0**2/PI
   44 CONTINUE
      DO 19 I=1,NST
   19 F(I)=XSW(I)-AA
C
C     CALCULATE TIME INCREMENT
C
      DT=(WLG/ABS(CEL-SP*COS(BETA)))/DT
      DT=DT*SP/WL
C
C     NON DIMENSIONALIZE INPUT
C
      DENOM=0.5*RHO*WL**5
      AIX=AIX/DENOM
      AIY=AIY/DENOM
      AIZ=AIZ/DENOM
      AM=AM/(0.5*RHO*WL**3)
      Z=Z/WL
      XLG=AA/WL
      XFG=1.-XLG
      XARM=XARM/WL
      ZARM=ZARM/WL
      DO 20 I=1,NJLT
   20 YARM(I)=YARM(I)/WL
      DO 21 I=1,NST
   21 XSW(I)=XSW(I)/WL
      WRITE(6,227) SP,AM,AIX,AIY,AIZ,FROUDE
C
C     CALCULATE N1,N2,DEL1,DEL2
C
      NSTI=NST-1
      DO 5  I=2,NSTI
      ISAVE=I
      DEL1=XSW(I)-XSW(I-1)
      DEL1=DEL1*WL
      DEL2=XSW(I+1)-XSW(I)
      DEL2=DEL2*WL
      IF(ABS(1.-DEL2/DEL1).GT.0.1) GO TO 6
    5 CONTINUE
    6 N1=ISAVE
      N2=NST-ISAVE+1
C
C     CALCULATE AC,DEM FOR PRESSURE
```

AD-A034 491 TETRA TECH INC PASADENA CALIF F/G 13/10
VULNERABILITY OF SURFACE EFFECT VEHICLES TO EXPLOSION-GENERATED--ETC(U)
NOV 76 R B WADE, S WANG, T W WIER N00014-76-C-0261
UNCLASSIFIED TETRAT-TC-645 NL

2 OF 2
AD
A034491

END
DATE
FILMED
2-77

```
C
      AC=2.*BB*XSW(N1)*WL
      DEM=0.5*RHO*WL**2*SP**2
C
C     CALCULATE FO AT CG
C
      DO 3 I=2,NST
      FO1=ABS(AA-XSW(I-1)*WL)
      FO2=ABS(AA-XSW(I)*WL)
      IF(FO2.LT .FO1) KFO=I
    3 CONTINUE
C
C     READ AND WRITE NON DIMENSIONAL DERIVATIVES
C
 1000 IF(L.EQ.2) GO TO 1001
      IPDER=0
      THTOPR=THTO/DTR
      WRITE(6,209) CCO,THTOPR
      CALL DER(AA,BB,CCO,DD,THTO,PHI,NST,N1,N2,DEL1,DEL2,HSW,NSW,XSW,
     *D1,W1,W2,RHO,WL)
      CALL GEO(AA,BB,CCO,DD,WL,NST,THTO,KFO,FO)
      GO TO 1002
      ENTRY SECDER
 1001 THTPR=THT/DTR
      IF(INT.EQ.0) IPDER=1
      CALL DER(AA,BB,CCX,DD,THTO,PHI,NST,N1,N2,DEL1,DEL2,HSW,NSW,XSW,
     *D1,W1,W2,RHO,WL)
      CALL GEO(AA,BB,CCX,DD,WL,NST,THTO,KFO,FO)
C
C     CALCULATE SPRAYL
C
 1002 N11=N1+1
      DO 14 I=1,NST
      ISAV=I-1
      IF(ENTRCE(I).NE.0.0) GO TO 15
   14 CONTINUE
   15 SPRAYL=(XSW(N11)-XSW(ISAV))*WL
      SX=0.0
      SY=0.0
      SK=0.0
      SN=0.0
      CALL FIN(SX,SY ,SK,SN,CR,CT,S,OMEGA)
      SFYV=DYV+FINYV
      SFYR=DYR+FINYR
      SFKV=DKV+FINKV
      SFKR=DKR+FINKR
      SFNV=DNV+FINNV
      SFNR=DNR+FINNR
      SC=DYV*DNR-(DYR-AM)*DNV
      SCF=SFYV*SFNR-(SFYR-AM)*SFNV
      IF(IPDER.NE.0) RETURN
      IF(IPDER.NE.0) WRITE(6,209) CCX,THTOPR
      WRITE(6,228)
      WRITE(6,229) DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      WRITE(6,233)
      WRITE(6,234) FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
```

```
      WRITE(6,235)
      WRITE(6,236) SFYV,SFYR,SFKV,SFKR,SFNV,SFNR
      WRITE(6,237) SC
      WRITE(6,238) SCF
C
C     WRITE CUMULATIVE INTEGRALS
C
      WRITE(6,231) FO
      WRITE(6,232)
      WRITE(6,233) (I,DI(I),DFI(I),DF2I(I),DF3I(I),DCI(I),DC2I(I),
     *DC3I(I),DCFI(I),DCF2I(I),DC2FI(I),B3BI(I),I=1,NST)
C
C     CONVERT TO DEGREES
C
      DO33 I=1,5
   33 PHO(I)=PHO(I)/DTR
      WRITE (6,239)
      WRITE(6,240)  (PHO(I),GI(I),SI(I),S1(I),TDRAF(I),I=1,5)
C
C     CONVERT  TO RADIANS
C
      DO63 I=1,5
   63 PHO(I)=PHO(I)*DTR
C
C     FORMATS
C
  100 FORMAT(8F10.2)
  101 FORMAT(F10.0,14I5)
  102 FORMAT(16I5)
  103 FORMAT(20A4)
  200 FORMAT(1H1,10HINPUT DATA //)
  201 FORMAT(1X,20A4)
  202 FORMAT(  1X,57HDT,NSTEP,NPRNT,IP,IFIN,IPLOT,IPT,NJET,INT,IBUG,IW,I
     *PR,ICO /F10.2,12I5)
  203 FORMAT(1X,17HTHT,PHI,PSI,Z           /8F10.2)
  204 FORMAT(  1X,31HAA,BB,CC,DD,AM,DXDU,AIX,AIZ,AIY/
     *4F10.3,F10.1,F10.3,3F10.1)
  205 FORMAT(  1X,23HAL,SP,RHO,ANU,COLL,CDNN/3F10.3,F12.9,2F10.3)
  207 FORMAT(1X,13HOMEGA,CR,CT,S     /8F10.2)
  208 FORMAT(  1X,20HCCO,THTO,SPTURN,DFTH  /8F10.2)
  209 FORMAT(1H1,6HDRAFT=,F6.2,10X,5HTRIM=,F6.2)
  210 FORMAT(  1X,14HXARM,ZARM,BACE  /8F10.2)
  211 FORMAT(  1X,8HYARM(I) )
  212 FORMAT(  1X,9HDELJET(I) )
  213 FORMAT(   1X,7HRMCP(I) )
  214 FORMAT(  1X,10HALPHA(I)      )
  215 FORMAT(1X,3HNSI /I5)
  216 FORMAT(1X,      20HBUBL,BUBB,WALB,DEPTH /8F10.2)
  217 FORMAT(1X,18HSLBOW,SLSTRN,THETA /8F10.2)
  218 FORMAT(1X,8HDRISE(I)  )
  219 FORMAT(1X,9HENTRCE(I) )
  220 FORMAT(1X,8HCHINE(I) )
  221 FORMAT(1X,3HNSW)
  222 FORMAT(1X,3HXSW)
  223 FORMAT(1X,3HHSW)
  224 FORMAT(/I5,2X,2HD1,2X,8F11.3/(11X,8F11.3))
  225 FORMAT(7X,2HW1,2X,8F11.3/(11X,8F11.3))
  226 FORMAT(7X,2HW2,2X,8F11.3/(11X,8F11.3))
  227 FORMAT(/////1X,16HCONVERTED INPUT /1X,24HSP,AM,AIX,AIY,AIZ,FROUDE
     */6G12.4)
```

```
228 FORMAT(///1X,27HNON DIMENSIONAL DERIVATIVES   /)
229 FORMAT(1X,44HDYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW/10E12.4/
   *        1X,44HDZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW/10E12.4/
   *        1X,44HDKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW/10E12.4/
   *        1X,44HDMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW/10E12.4/
   *        1X,44HDNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW/10E12.4)
231 FORMAT( 1X,40HCENTER OF PRESSURE AT CENTER OF GRAVITY=  ,F10.2)
232 FORMAT(   /1X,3HSEC, 9X,2HDI,8X,3HDFI,7X,4HDF2I,7X,4HDF3I,
   *8X,3HDCI,7X,4HDC2I,7X,4HDC3I,7X,4HDCFI,6X,5HDCF2I,6X,5HDC2FI,
   *7X,4HB3BI)
233 FORMAT(I5,11E11.3)
234 FORMAT(/1X,23HSTABILIZER COEFFICIENTS
   *          /7H FINYV=,E13.4/7H FINYR=,E13.4/7H FINKV=,E13.4/
   *7H FINKR=,E13.4/7H FINNV=,E13.4/7H FINNR=,E13.4)
235 FORMAT(  /,1X,33HSHIP PLUS STABILIZER COEFFICIENTS    )
236 FORMAT(   6H SFYV=,E13.4/6H SFYR=,E13.4/ 6H SFKV=,E13.4/
   *6H SFKR=,E13.4/ 6H SFNV=,E13.4/6H SFNR=,E13.4)
237 FORMAT( /1X, 34HSTABILITY CRITERION FOR SHIP ONLY= ,E12.4)
238 FORMAT(  1X,38HSTABILITY CRITERION FOR SHIP PLUS FIN=  ,E12.4)
239 FORMAT(/////1X,21HGEOMETRICAL VARIABLES  /,1X,9HROLL(DEG)  ,
   *10X,2HGI,10X,2HSI,10X,2HS1,7X,5HTDRAF)
240 FORMAT(1X,F10.3,4G12.4)
241 FORMAT(1X,38HDWFT,WAMP,WPER,BETA,WDEP,XO,RO,ETAO,TO/9F10.2)
242 FORMAT(1X,34HLDIS,RHOWA,ATM,PHIO,PHI1,THTB,THTS/F8.2,F10.6,6F8.2)
    RETURN
    END
VV
```

```
      SUBROUTINE DER(AA,BB,CC,DD,THT,PHI,NST,N1,N2,DEL1,DEL2,HSW,NSW,
     *XSW,D1,W1,W2,RHO,WL)
      DIMENSION HSW(1),NSW(1),XSW(1)
      DIMENSION D(25),F(25)
      DIMENSION B(25),S(25),CSZ(25),TEMPA(25),TEMPR(25)
      DIMENSION D1(25,25),W1(25,25),W2(25,25)
      CCHECK=CC-BB*PHI
      PHI0=CC/BB
      F(N1)=XSW(N1)*WL-AA
      D(N1)=CC-HSW(N1)   -THT*F(N1)
      DO 1 M=1,NST
      F(M)=XSW(M)*WL-AA
      D(M)=CC-HSW(M)   -THT*F(M)
      IF(D(M).LT.0.) D(M)=0.
    1 CALL SECT(M,D,D1,NSW,W1,W2,B,S,CSZ)
      HGT=DD-CC
C     COMPUTE DERIVATIVES WITH RESPECT TO F
C     FORM INTEGRALS
C     INTEGRATE AXIALLY
      CALL INTEG(B,D,F,S,CSZ,N1,N2,DEL1,DEL2,NST,TEMPA,TEMPR)
      CALL NONDIM(BB,HGT,RHO,WL,B,D,F,CSZ,TEMPA,TEMPR)
      RETURN
      END
```

```
      SUBROUTINE SECT(I,D,D1,NSW,W1,W2,B,S,CSZ)
      DIMENSION B(25),S(25),CSZ(25),D1(25,25),W1(25,25),W2(25,25)
      DIMENSION D(1),NSW(1)
      FLINER(X,X2,X1,Y2,Y1)=Y1+(X-X1)*(Y2-Y1)/(X2-X1)
      B(I)=0.0
      S(I)=0.0
      CSZ(I)=0.0
      TEMP1=0.0
      DRAFT=D(1)
      JJ=NSW(I)
      KL1=0
      DO 1 J=2,JJ
      RD2=D1(I,J)
      RD1=D1(I,J-1)
      RW12=W1(I,J)
      RW11=W1(I,J-1)
      RW22=W2(I,J)
      RW21=W2(I,J-1)
      IF(DRAFT.LE.0.0) GO TO 4
      IF(DRAFT.GE.D1(I,J)) GO TO 2
      RW12=FLINER(DRAFT,RD2,RD1,RW12,RW11)
      RW22=FLINER(DRAFT,RD2,RD1,RW22,RW21)
      KL1=1
      RD2=DRAFT
C
C     CALCULATE AREA,GIRDER,AND BEAM
C
    2 DELD=RD2-RD1
      W1D=RW12-RW11
      W2D=RW22-RW21
      DELS=0.5*DELD*(RW12+RW11+RW22+RW21)
      B(I)=RW12+RW22
      S(I)=S(I)+DELS
      BJM1=RW11+RW21
C
C     CALCULATE CENTROID FOR AREA ABOUT Y-AXIS
C
      TD2=D(I)-RD2
      SMOM=(TD2+0.5*DELD)*BJM1*DELD+
     *(TD2+DELD/3.)*0.5*DELD*(W1D+W2D)
      TEMP1=TEMP1+SMOM
      IF(KL1.EQ.1) GO T O 3
    1 CONTINUE
    3 CSZ(I)=TEMP1/S(I)
    4 RETURN
      END
vv
```

```
      SUBROUTINE INTEG(B,D,F,S,CSZ,N1,N2,DEL1,DEL2,NST,TEMPA,TEMPR)
      DIMENSION TEMPA(25),TEMPR(25),B2(25),B2F(25),B2F2(25),B2CSZ(25),
     *B2FCSZ(25),B2DDF(25),B2FDDF(25),D2(25),D2F(25),D2F2(25),
     *D2CSZ(25),D2CSZ2(25),D2DDF(25),D2FCSZ(25),DCSZDF(25),D2FDDF(25)
     *,D2CZDF(25)
      COMMON /INTEGL/ B2I,B2FI,B2F2I,B2CSZI,BFCSZI,B2DDFI,BFDDFI,
     *D2I,D2FI,D2CSZI,DCSZ2I,D2DDFI,DFCSZI,DFDDFI,D2F2I,DCZDFI
      DIMENSION B(1),D(1),F(1),S(1),CSZ(1)
C
C     COMPUTE DERIVATIVES OF D AND CSZ WITH RESPECT TO F
C
      N11=N1-1
      DCSZDF(1)=(CSZ(2)-CSZ(1))/DEL1
      DCSZDF(N1)=(CSZ(N1)-CSZ(N11))/DEL1
      DO 1 I=2,N11
    1 DCSZDF(I)=0.5*(CSZ(I+1)-CSZ(I-1))/DEL1
      N21=N1+1
      N22=NST-1
      DCSZDF(NST)=(CSZ(NST)-CSZ(N22))/DEL2
      DO 2 I=N21,N22
    2 DCSZDF(I)=0.5*(CSZ(I+1)-CSZ(I-1))/DEL2
C
C     COMPUTE AND STORE VARIABLES FOR AXIAL INTEGRATION.
C
      DO 3 I=1,NST
      IF(B(I).EQ.0.0.OR.D(I).EQ.0.0) TEMPR(I)=1.0
      IF(B(I).EQ.0.0.OR.D(I).EQ.0.0) GO TO 4
      TEMPR(I)=S(I)/B(I)/D(I)
    4 TEMPA(I)=2.4*TEMPR(I)+0.4
      B2(I)=B(I)*B(I)*TEMPR(I)
      B2F(I)=B2(I)*F(I)
      B2F2(I)=B2F(I)*F(I)
      B2CSZ(I)=B2(I)*CSZ(I)
      B2FCSZ(I)=B2F(I)*CSZ(I)
      B2DDF(I)=B2(I)*DCSZDF(I)
      B2FDDF(I)=B2DDF(I)*F(I)
      D2(I)=D(I)*D(I)*TEMPA(I)
      D2F(I)=D2(I)*F(I)
      D2F2(I)=D2F(I)*F(I)
      D2CSZ(I)=D2(I)*CSZ(I)
      D2CSZ2(I)=D2CSZ(I)*CSZ(I)
      D2DDF(I)=D2(I)*DCSZDF(I)
      D2FCSZ(I)=D2F(I)*CSZ(I)
      D2FDDF(I)=D2DDF(I)*F(I)
    3 D2CZDF(I)=D2(I)*CSZ(I)*DCSZDF(I)
C
C     PERFORM AXIAL INTEGRATION
C
      Q1=0.
      Q2=0.
      Q3=0.
      Q4=0.
      Q5=0.
      Q6=0.0
      Q7=0.0
      Q8=0.0
      Q9=0.0
      Q10=0.0
      Q11=0.0
      Q12=0.0
```

```
      SUBROUTINE NONDIM(BB,HGT,RHO,WL,B,D,F,CSZ,TEMPA,TEMPR)
      REAL         K1P ,K1Q ,K1W ,K1DP,K1DQ,K1DW,M1P ,M1Q ,M1W ,M1DP,
     *             M1DQ,M1DW,
     *             K2P ,K2Q ,K2W ,K2DP,K2DQ,K2DW,N2P ,N2Q ,N2W ,N2DP,
     *             N2DQ,N2DW,
     *             K3P ,K3R ,K3V ,K3DP,K3DR,K3DV,N3P ,N3R ,N3V ,N3DP,
     *             N3DR,N3DV,
     *             K4P ,K4R ,K4V ,K4DP,K4DR,K4DV,M4P ,M4R ,M4V ,M4DP,
     *             M4DR,M4DV,
     *             L2  ,L3  ,L4  ,L5
      DIMENSION B(1),D(1),F(1),CSZ(1),TEMPA(1),TEMPR(1)
      COMMON /INTEGL/ B2I,B2FI,B2F2I,B2CSZI,BFCSZI,B2DDFI,BFDDFI,
     *D2I,D2FI,D2CSZI,DCSZ2I,D2DDFI,DFCSZI,DFDDFI,D2F2I,DCZDFI
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      PI=3.1415927
      AKY=1.
      AKZ=1.
      H= 0.25*PI*RHO
      C1= H
      C2= C1*AKY
      C3= H
      C4= C3*AKZ
      L2= 0.5*RHO*WL**2
      L3= L2*WL
      L4= L3*WL
      L5= L4*WL
      Z1DW= -B2I*C1
      Z1DP=BB*Z1DW
      Z1Q =(B(1)**2*F(1))*C1*TEMPR(1)
      Z1DQ= B2FI*C1
      Z1W= -B(1)**2*C1*TEMPR(1)
      Z1P = BB*Z1W
      M1DW= B2FI*C1
      M1DP= BB*M1DW
      M1Q =(-B(1)**2*F(1)**2*TEMPR(1)-B2FI)*C1
      M1DQ= -B2F2I*C1
      M1W = (B(1)**2*F(1)*TEMPR(1)+B2I)*C1
      M1P = BB*M1W
      K1DW= BB*Z1DW
      K1DP= BB*Z1DP
      K1Q = BB*Z1Q
      K1DQ= BB*Z1DQ
      K1W = BB*Z1W
      K1P = BB*Z1P
      Y2DW= -B2I*C2
      Y2DP= BB*Y2DW
      Y2Q = (B(1)**2*F(1))*C2*TEMPR(1)
      Y2DQ= B2FI*C2
      Y2W = -B(1)**2*C2*TEMPR(1)
      Y2P = BB*Y2W
      N2DW= -B2FI*C2
      N2DP= BB*N2DW
      N2Q = (B(1)**2*F(1)**2*TEMPR(1)+B2FI)*C2
      N2DQ= B2F2I*C2
      N2W = (-B(1)**2*F(1)*TEMPR(1)-B2I)*C2
      N2P = BB*N2W
```

```
K2DW= B2CSZI*C2-HGT*Y2DW
K2DP= BB*K2DW-HGT*Y2DP
K2Q = (-B(1)**2*F(1)*CSZ(1)*TEMPR(1)-BFDDFI)*C2-HGT*Y2Q
K2DQ= -BFCSZI*C2-HGT*Y2DQ
K2W = (B(1)**2*CSZ(1)*TEMPR(1)+B2DDFI)*C2-HGT*Y2W
K2P = BB*K2W-HGT*Y2P
Y3DV= -D2I*C3
Y3R = (-D(1)**2*F(1))*C3*TEMPA(1)
Y3DR= -D2FI*C3
Y3DP= D2CSZI*C3
Y3V = -D(1)**2*C3*TEMPA(1)
Y3P = (D(1)**2*CSZ(1)*TEMPA(1)+D2DDFI)*C3
N3DV= -D2FI*C3
N3R = (-D(1)**2*F(1)**2*TEMPA(1)-D2FI)*C3
N3DR= -D2F2I*C3
N3DP= DFCSZI*C3
N3V = (-D(1)**2*F(1)*TEMPA(1)-D2I)*C3
N3P = (D(1)**2*F(1)*CSZ(1)*TEMPA(1)+D2CSZI+DFDDFI)*C3
K3DV= D2CSZI*C3-Y3DV*HGT
K3R = (D(1)**2*F(1)*CSZ(1)*TEMPA(1)+DFDDFI)*C3-Y3R*HGT
K3DR= DFCSZI*C3-Y3DR*HGT
K3DP= -DCSZ2I*C3-Y3DP*HGT
K3V = (D(1)**2*CSZ(1)*TEMPA(1)+D2DDFI)*C3-Y3V*HGT
K3P = (-D(1)**2*CSZ(1)**2*TEMPA(1)-2.*DCZDFI)*C3-Y3P*HGT
Z4DV= -D2I*C4
Z4R = (-D(1)**2*F(1))*C4*TEMPA(1)
Z4DR= -D2FI*C4
Z4DP= D2CSZI*C4
Z4V = -D(1)**2*C4*TEMPA(1)
Z4P = (D(1)**2*CSZ(1)*TEMPA(1)+D2DDFI)*C4
M4DV= D2FI*C4
M4R = (D(1)**2*F(1)**2*TEMPA(1)+D2FI)*C4
M4DR= D2F2I*C4
M4DP= -DFCSZI*C4
M4V = (D(1)**2* F(1)*TEMPA(1)+D2I)*C4
M4P = (-D(1)**2*CSZ(1)*F(1)*TEMPA(1)-D2CSZI-DFDDFI)*C4
K4DV= BB*Z4DV
K4R = BB*Z4R
K4DR= BB*Z4DR
K4DP= BB*Z4DP
K4V = BB*Z4V
K4P = BB*Z4P
DYP    = (Y2P+Y3P)/L3
DYQ    = Y2Q/L3
DYR    = Y3R/L3
DYV    = Y3V/L2
DYW    = Y2W/L2
DYDP    = (Y2DP+Y3DP)/L4
DYDQ    = Y2DQ/L4
DYDR    = Y3DR/L4
DYDV    = Y3DV/L3
DYDW    = Y2DW/L3
DZP    = (Z1P+Z4P)/L3
DZQ    = Z1Q/L3
DZR    = Z4R/L3
DZV    = Z4V/L2
DZW    = Z1W/L2
DZDP    = (Z1DP+Z4DP)/L4
DZDQ    = Z1DQ/L4
DZDR    = Z4DR/L4
```

```
DZDV    = Z4DV/L3
DZDW    = Z1DW/L3
DKP   = (K1P+K2P+K3P+K4P)/L4
DKQ   = (K1Q+K2Q)/L4
DKR   = (K3R+K4R)/L4
DKV   = (K3V+K4V)/L3
DKW   = (K1W+K2W)/L3
DKDP    =(K1DP+K2DP+K3DP+K4DP)/L5
DKDQ    =(K1DQ+K2DQ)/L5
DKDR    = (K3DR+K4DR)/L5
DKDV    = (K3DV+K4DV)/L4
DKDW    = (K1DW+K2DW)/L4
DMP   = (M1P+M4P)/L4
DMQ   = M1Q/L4
DMR   = M4R/L4
DMV   = M4V/L3
DMW   = M1W/L3
DMDP    = (M1DP+M4DP)/L5
DMDQ    = M1DQ/L5
DMDR    = M4DR/L5
DMDV    = M4DV/L4
DMDW    = M1DW/L4
DNP   = (N2P+N3P)/L4
DNQ   = N2Q/L4
DNR   = N3R/L4
DNV   = N3V/L3
DNW   = N2W/L3
DNDP    = (N2DP+N3DP)/L5
DNDQ    = N2DQ/L5
DNDR    = N3DR/L5
DNDV    = N3DV/L4
DNDW    = N2DW/L4
DYW=DYQ=DZV=DZP=DZR=DKW=DKQ=DMV=DMP=DMR=DNW=DNQ=0.
DYDW=DYDQ=DZDV=DZDP=DZDR=DKDW=DKDQ=DMDV=DMDP=DMDR=DNDW=DNDQ=0.
DYV=2.*DYV
DYP=2.*DYP
DYR=2.*DYR
DZW=2.*DZW
DZQ=2.*DZQ
DKV=2.*DKV
DKP=2.*DKP
DKR=2.*DKR
DMW=2.*DMW
DMQ=2.*DMQ
DNV=2.*DNV
DNP=2.*DNP
DNR=2.*DNR
DYDV=2.*DYDV
DYDP=2.*DYDP
DYDR=2.*DYDR
DZDW=2.*DZDW
DZDQ=2.*DZDQ
DKDV=2.*DKDV
DKDP=2.*DKDP
DKDR=2.*DKDR
DMDW=2.*DMDW
DMDQ=2.*DMDQ
DNDV=2.*DNDV
DNDP=2.*DNDP
DNDR=2.*DNDR
```

```
      RETURN
      END
```

```
      SUBROUTINE GEO(AA,BB,CC,DD,WL,NST,THT,KFO,FO)
      DIMENSION B(25),CSZ(25),F(25),G(25),S(25),DF(25),DF2(25),DF3(25),
     *DCSZ(25),DCSZ2(25),DCSZ3(25),DCSZF(25),DCSZF2(25),DCSZ2F(25)
     *,D(25)
      COMMON /ABC/ DRAFT(25)
      COMMON /CDE/ DRISE(23),ENTRCE(23),CHINE(23),HSPRAY(23)
      COMMON /GEOMM/NSW(25),W1(25,25),W2(25,25),D1(25,25)
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      COMMON /U/ GI(25),SI(25),S1(25),PHO(25),TDRAF(25)
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
C
C     STATEMENT FUNCTION FOR TRAPEZOIDAL INTEGRATION
C
      TRAP(H,Y1,Y2)=0.5*H*(Y1+Y2)
C
C
C     STATEMENT FUNCTION FOR LINEAR INTERPOLATION
C
      STATE(X,X2,X1,Y2,Y1)=Y1+(X-X1)*(Y2-Y1)/(X2-X1)
C     CONSTANTS
C
      WL2=WL*WL
      WL3=WL2*WL
      WL4=WL3*WL
      WL5=WL4*WL
      BSTART=BB
      CSTART=CC
      DTR=3.1415927/180.
      PHIZ=2.*DTR
      DELTA=1.*DTR
      DO 999 K=1,5
      BB=BSTART
      CC=CSTART
      PHI=PHIZ-(K-1)*DELTA
      PHO(K)=PHI
      CCHECK=CSTART-BB*PHI
      PHIO=CSTART/BB
C     CALCULATE DRAFT AND CC
C
      F(N1)=XSW(N1)*WL-AA
      D(N1)=CC-HSW(N1)  -THT*F(N1)+BB*PHI
      DO 9 M=1,NST
      CC=CSTART
      F(M)=XSW(M)*WL-AA
      D(M)=CC-HSW(M)  -THT*F(M)+BB*PHI
      IF(D(1).LE.0.0) D(M)=-THT* XSW(M)*WL+HSW(1)-HSW(M)  +BB*PHI
      IF(D(1).LE.0.)CC=-AA*THT+HSW(1)  +BB*PHI
      IF(D(N1).LE.0.)D(M)=THT*(XSW(N1)-XSW(M))*WL+HSW(N1)-HSW(M)+BB*PHI
      IF(D(N1).LE.0.0) CC=(XSW(N1)*WL-AA)*THT  +BB*PHI
      IF(D(1).GT.0.0.AND.D(N1) .GT.0.0) CC=CC+BB*PHI
      IF(D(1).GT.0.0.AND.D(N1) .GT.0.0.AND.THT.EQ.0.0.AND.CCHECK.LE.0.0)
     *CC=PHIO*BB+CSTART+(PHI-PHIO)*2.*BB
      IF(D(M).LE.0.0) D(M)=0.0
      IF(K.EQ.3) DRAFT(M)=D(M)
      IF(K.EQ.3) CCO=CC
C
C     CALCULATE GIRDER AND CROSS SECTIONAL AREA
C
      I=M
```

```
      DRFT=D(M)
      CSZ(I)=0.0
      B(I)=0.0
      G(I)=W1(I,1)+W2(I,1)
      S(I)=0.0
      TEMP1=0.
      DF(I)=0.
      DF2(I)=0.
      DF3(I)=0.
      DCSZ(I)=0.
      DCSZ2(I)=0.
      DCSZ3(I)=0.
      DCSZF(I)=0.
      DCSZF2(I)=0.
      DCSZ2F(I)=0.
      JJ=NSW(I)
      KL1=0
      DO 8  J=2,JJ
      RD2=D1(I,J)
      RD1=D1(I,J-1)
      RW12=W1(I,J)
      RW11=W1(I,J-1)
      RW22=W2(I,J)
      RW21=W2(I,J-1)
      IF(DRFT .LE.0.0) GO TO 9
      IF(DRFT .GE.D1(I,J)) GO TO 7
      RW12=STATE(DRFT ,RD2,RD1,RW12,RW11)
      RW22=STATE(DRFT ,RD2,RD1,RW22,RW21)
      KL1=1
      RD2=DRFT
    7 DELD=RD2-RD1
      DELD2=DELD*DELD
      W1D=RW12-RW11
      W2D=RW22-RW21
      DELS=0.5*DELD*(RW12+RW11+RW22+RW21)
      DELG1=SQRT(W1D*W1D+DELD2)
      DELG2=SQRT(W2D*W2D+DELD2)
      DELG=DELG1+DELG2
      B(I)=RW12+RW22
      BJM1=RW11+RW21
      TD2=D(I)-RD2
      SMOM=(TD2+0.5*DELD)*BJM1*DELD+(TD2+DELD/3.)*0.5*DELD*(W1D+W2D)
      TEMP1=TEMP1+SMOM
      S(I)=S(I)+DELS
      G(I)=G(I)+DELG
      CSZ(I)=TEMP1/S(I)
      IF(KL1.EQ.1) GO TO 12
    8 CONTINUE
   12 IF(K.NE.3) GO TO 9
      DF(I)=D(I)*F(I)
      DF2(I)=DF(I)*F(I)
      DF3(I)=DF2(I)*F(I)
      PARM=CSZ(I)+DD-D(I)
      DCSZ(I)=D(I)*PARM
      DCSZ2(I)=DCSZ(I)*PARM
      DCSZ3(I)=DCSZ2(I)*PARM
      DCSZF(I)=D(I)*F(I)*PARM
      DCSZF2(I)=DCSZF(I)*F(I)
      DCSZ2F(I)=DCSZF(I)*PARM
    9 CONTINUE
```

```
C
C     INTEGRATES FOR WETTED SURFACE AREA AND DISPLACEMENT
C
      Q1=0.0
      Q2=0.0
      NSTI=NST-1
      IF(N1.NE.NSTI) GO TO 10
      N1=N1+1
      GO TO 11
   10 CALL SIMPSO  (N2,DEL2,S(N1),Q1)
      CALL SIMPSO  (N2,DEL2,G(N1),Q2)
   11 CALL SIMPSO  (N1,DEL1,S(1),R1)
      CALL SIMPSO  (N1,DEL1,G(1),R2)
      SI(K)=(Q1+R1)/WL3
      GI(K)=(Q2+R2)/WL2
      S1(K)=S(1)/WL2
      TDRAF(K)=D(1)/WL
      IF(K.NE.3) GO TO 999
      DI(1)=0.
      DFI(1)=0.
      DF2I(1)=0.
      DF3I(1)=0.
      DCI(1)=0.
      DC2I(1)=0.
      DC3I(1)=0.
      DCFI(1)=0.
      DCF2I(1)=0.
      DC2FI(1)=0.
      B3BI(1)=0.
      FO=CSZ(KFO)+DD-D(KFO)
      DO 1 I=2,NST
      H=XSW(I)-XSW(I-1)
      H=H*WL
      A1=TRAP(H,D(I),D(I-1))
      A2=TRAP(H,DF(I),DF(I-1))
      A3=TRAP(H,DF2(I),DF2(I-1))
      A4=TRAP(H,DF3(I),DF3(I-1))
      A5=TRAP(H,B(I),B(I-1))
      A6=TRAP(H,DCSZ2(I),DCSZ2(I-1))
      A7=TRAP(H,DCSZ(I),DCSZ(I-1))
      A8=TRAP(H,DCSZF(I),DCSZF(I-1))
      A9=TRAP(H,DCSZF2(I),DCSZF2(I-1))
      A10=TRAP(H,DCSZ3(I),DCSZ3(I-1))
      A11=TRAP(H,DCSZ2F(I),DCSZ2F(I-1))
      DI(I)=DI(I-1)+A1/WL2
      DFI(I)=DFI(I-1)+A2/WL3
      DF2I(I)=DF2I(I-1)+A3/WL4
      DF3I(I)=DF3I(I-1)+A4/WL5
      DCI(I)=DCI(I-1)+A7/WL3
      DC2I(I)=DC2I(I-1)+A6/WL4
      DC3I(I)=DC3I(I-1)+A10/WL5
      DCFI(I)=DCFI(I-1)+A8/WL4
      DCF2I(I)=DCF2I(I-1)+A9/WL5
      DC2FI(I)=DC2FI(I-1)+A11/WL5
      B3BI(I)=B3BI(I-1)+BB**3*A5/WL5
    1 CONTINUE
  999 CONTINUE
      CC=CCO
      RETURN
      END
```

```
      SUBROUTINE FIN(SX,SY,SK,SN,CR,CT,S,OMEGA)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO,U2
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /FCOEF/ FYNCL,FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
      COMMON /FINVOR/ A,BBP,DELI,TCBAR,XFN,DDP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,DUMMY,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,COLL,CDNN,FROUDE,CC,DD,ANU,ALUD,CLD
      COMMON /LIFT/ ETA(30),CLIFT,GAMMA,XLAM
      COMMON /TVCC/ XARM,ZARM,BACE,YARM(4),DELJET(4),RMCP(4),NJET
      U2=U**2
      IF(SX.NE.0.0) GO TO 5
      NE=11
      CLIFT=0.2*PI
      SINO=SIN(OMEGA)
      COSO=COS(OMEGA)
      TCBAR=0.1
      CBAR=(CR+CT)/2
      A=CBAR*S
      AR=S**2/A
      XLAM=CT/CR
      GAMMA=ATAN(0.75*CR*(1.-XLAM)/S)
      BBP=BB-S*SINO/2.
      DDP=DD+S*COSO/2.+BACE
      XFN=-(XLG-CBAR/(2.*WL))
      DEL=S/(NE-1)
      DELI=1./(NE-1)
      ETA(1)=0.0
      DO 4 I=2,NE
    4 ETA(I)=ETA(I-1)+DEL
      VORX=0.0
      VORY=0.0
      VORK=0.0
      VORN=0.0
      CALL FINCOF(CR,CT,S,OMEGA)
    5 IF(THT.GE.0.0) GO TO 10
      BETA=-(V+XFG*R)/U
      CALL VORTEX(VORX,VORY,VORK,VORN,BETA ,CR,CT,S,OMEGA)
   10 FBETA=-(V+XFN*R)*COSO/U
      RN=U*CBAR/ANU*SP
      CF=0.044/(RN**0.1666)
      CD=0.125*PI*TCBAR**2
      DRAG=(CD+2.*CF+(FYNCL*FBETA)**2/(PI*AR))*A/WL**2*U2
      FINX=-2.*DRAG
      SX=FINX+VORX
      SY=(FINYV*V+FINYR*R)*U+VORY
      SK=(FINKV*V+FINKR*R)*U+VORK
      SN=(FINNV*V+FINNR*R)*U+VORN
      RETURN
      END
```

```
      SUBROUTINE FINCOF(CR,CT,S,OMEGA)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO,U2
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /FCOFF/ FYNCL,FINYV,FINYR,FINKV,FINKR,FINNV,FINNR
      COMMON /FINVOR/ A,BBP,DELI,ICBAR,XFN,DDP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
      IVOR=0
      CALL LIFTC(0.,CL,CL,CR,CT,S,OMEGA,IVOR)
      FYNCL=CL
      FBC=COSO/UO
      FINLV=CL*A/WL**2*UO**2*FBC
      FINLR=FINLV*XFN
      SFV=FINLV*COSO
      SFR=FINLR*COSO
      VFV=FINLV*SINO
      VFR=FINLR*SINO
      FINYV=-2.*SFV
      FINYR=-2.*SFR
      FINKV=-2.*VFV*BBP/WL+2.*SFV*DDP/WL
      FINKR=-2.*VFR*BBP/WL+2.*SFR*DDP/WL
      FINNV=FINYV*XFN
      FINNR=FINYR*XFN
      RETURN
      END
```

```
      SUBROUTINE LIFTC(BETA,CL,CLR,CR,CT,S,OMEGA,IVOR)
      DIMENSION CLC(30),CLCR(30)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO,U2
      COMMON /B/ P,Q,R,X,YY,Z,U,V,DUM,PHI,THT,PSI
      COMMON /FINVOR/ A,BBP,DELI,TCBAR,XFN,DDP
      COMMON /LIFT/ ETA(30),CLIFT,GAMMA,XLAM
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FU,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
      W=0.0
      WP=0.0
      ALPHA=1.0
      ALPHAR=1.
      DO 40 L=1,NE
      IF(IVOR.EQ.0) GO TO 20
      IF(BETA.EQ.0.0) GO TO 19
C
C     CALCULATE SIDEWALL PARAMETERS
C
      SINT=SIN(THT)
      DT=CC+AA*SINT
      DF=CC-(WL-AA)*SINT                                                C
      D=DF
      IF(DT.GE.0.0) GO TO 10
      D=-WL*SINT                                                        C
      DT=0.0
   10 D2=D**2
C
C     CALCULATE LIFT ON SIDEWALL
C
      XLIFT=CLIFT*U2*D2*BETA                                            C
C
C     CALCULATE VORTEX STRENGTH AND POSITION
C
      SINB=SIN(ATAN(BETA))                                              C
      H=0.25*PI*D
      GRK=XLIFT/(U*H)
      Y1=SINB*WL                                                        C
      Y2=ETA(L)*SINO
      Y=Y1+Y2
      YP=Y1-Y2
      C1=ETA(L)*COSO
      C2=H-C1-DT
      C3=H+C1+DT
      R1=SQRT(C2**2+Y**2)
      R1P=SQRT(C2**2+YP**2)
      Q1=GRK/(2.*PI*R1)
      Q1P=GRK/(2.*PI*R1P)
      IF(Y.EQ.0.0) XMU1=PI*0.5
      IF(Y.EQ.0.0) GO TO 22
      XMU1=ATAN(ABS(C2/Y))
   22 W1=Q1*SIN(XMU1-OMEGA)
      IF(YP.EQ.0.0) XMU1=PI*0.5
      IF(YP.EQ.0.0) GO TO 23
      XMU1=ATAN(ABS(C2/YP))
   23 W1P=Q1P*SIN(XMU1-OMEGA)
C
C     SIDEWASH CALCULATION FOR IMAGE VORTEX
C
      R2=SQRT(C3**2+Y**2)
      R2P=SQRT(C3**2+YP**2)
```

```
      Q2= GRK/(2.*PI*R2)
      Q2P=GRK/(2.*PI*R2P)
      IF(Y.EQ.0.0) XMU2=PI*0.5
      IF(Y.EQ.0.0) GO TO 11
      XMU2=ATAN(ABS(C3/Y))
   11 W2=Q2*SIN(XMU2+OMEGA)
      IF(YP.EQ.0.0) XMU2=PI*0.5
      IF(YP.EQ.0.0) GO TO 12
      XMU2=ATAN(ABS(C3/YP))
   12 W2P=Q2P*SIN(XMU2+OMEGA)
      W=W1+W2
      WP=W1P+W2P
   19 ALPHA=-WP/U
      ALPHAR=-W/U
C
C     CALCULATE FORCE ON FINS
C
   20 CETA=CR-CR*ETA(L)*(1.-XLAM)/S
      CLOR= AR/(2.+AR)*2.*PI*ALPHAR
      CLO = AR/(2.+AR)*2.*PI*ALPHA
      CLCR   (L)=0.5*(CETA/CBAR+((4./PI)*SQRT(1-(ETA(L)/S)**2))
     *     -(1.-ETA(L)/S)*(4.*(1.-COS(GAMMA))))*CLOR
      CLC    (L)=0.5*(CETA/CBAR+((4./PI)*SQRT(1-(ETA(L)/S)**2))
     *     -(1.-ETA(L)/S)*(4.*(1.-COS(GAMMA))))*CLO                C
   40 CONTINUE
      CALL SIMPSO(NE,DELI,CLC    ,CL)
      CALL SIMPSO(NE,DELI,CLCR   ,CLR)
      RETURN
      END
vv
```

```
      SUBROUTINE VORTEX(SX,SY,SK,SN,BETA,CR,CT,S,OMEGA)
      COMMON /ALL/ AR,CBAR,COSO,NE,SINO,U2
      COMMON /FINVOR/ A,BBP,DELI,TCBAR,XFN,DDP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DIR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
      IVOR=1
      CALL LIFTC(BETA,CL,CLR,CR,CT,S,OMEGA,IVOR)
      FINLR=CLR*A/WL**2*U2
      FINL=CL*A/WL**2*U2
      DRAGR=CLR**2/(PI*AR)*A/WL**2*U2
      DRAG=CL**2/(PI*AR)*A/WL**2*U2
      SFR=FINLR*COSO
      SF=FINL*COSO
      SX=-(DRAG+DRAGR)
      VFR=FINLR*SINO
      VF=-FINL*SINO
      SY=SF+SFR
      SN=SY*XFN+(DRAGR-DRAG)*BBP/WL
      SK=(VFR-VF)*BBP/WL-SY*DDP/WL
      RETURN
      END
```

```
      SUBROUTINE DERIVE(T,N,Y,YP)
      REAL KC,MC,NC
      DIMENSION A(6,5),B(5)
      DIMENSION A1(4,3),B1(3)
      DIMENSION Y(12),YP(12)
      COMMON /A/ PDOT,QDOT,RDOT,PHIDOT,THTDOT,PSIDOT,UDOT,VDOT,WDOT,
     *XDOT,YDOT,ZDOT
      COMMON /ABC/ DRAFT(25),WEIGHT,DUMMIE(5),THETA
      COMMON /B/ P,Q,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDG,DNDR,DNDV,DNDW
      COMMON /DERV/ NK,DELTA,FX,FY,FK,FN,XUDELU,DRAGY,DRAGN,
     *DELTAY,DELTAN,DRACK,BETAR,DFTH,DELTAX,DELTAK,DFTHI,THRATE
     *,DELP,DELS,RPM,IFOIL,IFIN
      COMMON /FOYL/ C,ALFA,GAMA,XF
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALUD,CLD
     *,NO,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /PRES/ CDIS,RHOWA,PHIO,PHI1,ATM,PMAX,AC,DEM
      COMMON /TEMP/ SX,SY,SK,SN
      COMMON /TEMPI/ THIGH,TLOW,SHIPDG,TOTLDG,TX
      COMMON/Y/ DNPHI,DKPHI,DYPHI,DELN,DELK,DELY
      COMMON /INDER/ CR,CT,S,OMEGA
      COMMON /IVCC/ XARM,ZARM,BACE,YARM(4),DELJET(4),RMCP(4),NJET
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      COMMON /VLDOT/ VOLDOT
      COMMON /VOLM/ VOLP
      COMMON /TUVW/ PWM,PWZ,PMC,PZC,PSLZ,PSLM
      COMMON /PSEAL/ THTB,THTS
      COMMON /FLOW/ PC,QF,QO,VDOTP,AOP,AI
      U=Y(1)
      V=Y(2)
      W=Y(3)
      P=Y(4)
      Q=Y(5)
      R=Y(6)
      X=Y(7)
      YY=Y(8)
      Z=Y(9)
      PHI=Y(10)
      THT=Y(11)
      PSI=Y(12)
      BETAR=-ATAN((V-XLC*R)/U)
      CALL DRAG(DRAGY,DRAGK,DRAGN,P,R,V)
      IF(T.EQ.0.)
     *CALL AUXILY(PHI,U,XUDELU,DNPHIF,DKPHIF)
      IF(IFIN.NE.0) CALL FIN(SX,SY,SK,SN,CR,CT,S,OMEGA)
      CALL THRUST(U,THT,DFTH,TX,TY,TK,TN,SHIPDG,TOTLDG)
      ARWALL=2.*CC/WL
      ECOEF=0.9
      CDI=2.*(0.5*DYV*V*U)**2/(PI*ARWALL*ECOEF)
C
C     CALCULATE UDOT,VDOT,WDOT,PDOT,QDOT,RDOT
C
C
      A(1,1)=AM-DYDV
```

```
      A(1,2)=-DYDW
      A(1,3)=-DYDP
      A(1,4)=-DYDQ
      A(1,5)=-DYDR
      A(2,1)=-DZDV
      A(2,2)=AM-DZDW
      A(2,3)=-DZDP
      A(2,4)=-DZDQ
      A(2,5)=-DZDR
      A(3,1)=-DKDV
      A(3,2)=-DKDW
      A(3,3)=AIX-DKDP
      A(3,4)=-DKDQ
      A(3,5)=-DKDR
      A(4,1)=-DMDV
      A(4,2)=-DMDW
      A(4,3)=-DMDP
      A(4,4)=AIY-DMDQ
      A(4,5)=-DMDR
      A(5,1)=-DNDV
      A(5,2)=-DNDW
      A(5,3)=-DNDP
      A(5,4)=-DNDQ
      A(5,5)=AIZ-DNDR
      CALL LINVEL(FXLV,FYLV,FZLV,FKLV,FMLV,FNLV)
      CALL INERTIA(FXIC,FYIC,FZIC,FKIC,FMIC,FNIC)
      SZ=0.
      SM=0.
C     SET THRUST EQUAL TO SHIP DRAG AT T=0.
      IF(T.EQ.0) TXO=SHIPDG-SX
      TX=TXO
      TZ=0.
      TM=0.
      DRAGZ=0.
      DRAGM=0.
      DXPHIF=0.
      DYPHIF=0.
      DZPHIF=0.
      DMPHIF=0.
      DRAGX=XUDELU-SHIPDG
      CALL SEAWAV(WX,WY,WZ,WK,WM,WN,VOL,AO,Y,T)
      CALL DRAGV(DZ2,DM2,DK2,F,W,Q,2)
      CALL DRAGV(DZ3,DM3,DK3,F,W,Q,3)
      DZ=DZ2+DZ3
      DM=DM2+DM3
      DK=DK2+DK3
      VOLP=VOL
      CALL PRESS(T,Y,VOL,AO,XC,YC,ZC,KC,MC,NC)
      PWM=WM*DEM*WL/2240.
      PWZ=WZ*DEM/2240.
      PMC=MC*DEM*WL/2240.
      PZC=ZC*DEM/2240.
C
C     BOW SEAL FORCES AND MOMENTS WITH ROLL MOMENT
C
      HEV=Y(9)*WL
      NI=11
      TESTB=AMIN1(BETA/DTR+.0001,180.)
      IF(BETA.EQ.0..OR.TESTB.EQ.180.) NI=1
      DELSL=2.*BB/NI
```

```
      XSL=XFG*WL
      YSL=-(BB+0.5*DELSL)
      ZSL=DD-CC
      BOWZ=BOWK=BOWM=0.
      STNZ=SINM=STNK=0.
      PCGAGE=PC-ATM
      IF(PCGAGE.LT.0.) GO TO 3
      DO 1 II=1,NI
      YSL=YSL+DELSL
      CALL SWAVE(XSL,YSL,ZSL,Y,T,ETASL)
      DBOW=ETASL
      IF(DBOW.LE.0.) GO TO 1
      WBOW=DBOW/SIN(THTB)
      DELZ=-DELSL*WBOW*PCGAGE*COS(THTB)
      BOWZ=BOWZ+DELZ
      ARMX=XSL
      ARMY=YSL
      BOWM=BOWM-DELZ*ARMX
      BOWK=BOWK+DELZ*ARMY
    1 CONTINUE
C
C     STERN SEAL FORCES AND MOMENTS WITH ROLL MOMENT
C
      XSL=-XLG*WL
      YSL=-(BB+0.5*DELSL)
      DO 2 II=1,NI
      YSL=YSL+DELSL
      CALL SWAVE(XSL,YSL,ZSL,Y,T,ETASL)
      DSTN=ETASL
      IF(DSTN.LE.0.) GO TO 2
      WSTN=DSTN/SIN(THTS)
      HYDRO=0.5*RHO*G*DSTN
      DELZ=-DELSL*WSTN*PCGAGE*COS(THTS)
      STNZ=STNZ+DELZ
      ARMX=XSL
      ARMY=YSL
      STNM=STNM-DELZ*ARMX
      STNK=STNK+DELZ*ARMY
    2 CONTINUE
    3 CONTINUE
      PSLZ=BOWZ+STNZ
      PSLZ=PSLZ/2240.
      PSLM=BOWM+STNM
      PSLM=PSLM/2240.
      SLZ=(BOWZ+STNZ)/DEM
      SLK=(BOWK+STNK)/DEM/WL
      SLM=(BOWM+STNM)/DEM/WL
      WZ=WZ+SLZ
      WK=WK+SLK
      WM=WM+SLM
      XWGT=WEIGHT*SIN(THT)/DEM
      ZWGT=WEIGHT*COS(THT)/DEM
      FX=-AM*(Q*W-R*V)+FXLV+SX+FXIC+TX+DRAGX+DXPHIF-CDI+WX-XWGT+XC
      FY=-AM*(R*U-P*W)+FYLV+SY+FYIC+TY+DRAGY+DYPHIF+WY+YC
      FZ=-AM*(P*V-Q*U)+FZLV+SZ+FZIC+TZ+DRAGZ+DZPHIF+WZ+ZWGT+ZC+DZ
      FK=-(AIZ-AIY)*Q*R+FKLV+SK+FKIC+TK+DRAGK+DKPHIF+WK+KC+DK
      FM=-(AIX-AIZ)*R*P+FMLV+SM+FMIC+TM+DRAGM+DMPHIF+WM+MC+DM
      FN=-(AIY-AIX)*P*Q+FNLV+SN+FNIC+TN+DRAGN+DNPHIF+WN+NC
      B(1)=FY
      B(2)=FZ
```

```
      B(3)=FK
      B(4)=FM
      B(5)=FN
      NEQ=5
      CALL COMB(A,NEQ,6,B,1,NER,DET)
      UDOT=FX/(AM-DXDU)
      VDOT=B(1)
      WDOT=B(2)
      PDOT=B(3)
      QDOT=B(4)
      RDOT=B(5)
      YP(1)=UDOT
      YP(2)=VDOT
      YP(3)=WDOT
      YP(4)=PDOT
      YP(5)=QDOT
      YP(6)=RDOT
C
C     CALCULATE XDOT,YDOT,ZDOT
C
      COSTH=COS(THT)
      SINTH=SIN(THT)
      COSPHI=COS(PHI)
      SINPHI=SIN(PHI)
      COSPSI=COS(PSI)
      SINPSI=SIN(PSI)
      XDOT= U*COSTH*COSPSI+V*(SINTH*SINPHI*COSPSI-COSPHI*SINPSI)+
     *W*(SINTH*COSPHI*COSPSI+SINPHI*SINPSI)
      YDOT= U*COSTH*SINPSI+V*(SINTH*SINPHI*SINPSI+COSPHI*COSPSI)+
     *W*(SINTH*COSPHI*SINPSI-SINPHI*COSPSI)
      ZDOT=-U*SINTH+V*COSTH*SINPHI+W*COSTH*COSPHI
      YP(7)=XDOT
      YP(8)=YDOT
      YP(9)=ZDOT
C
C     CALCULATE PHIDOT,THTDOT,PSIDOT
C
      A1(1,1)=1.
      A1(1,2)=0.
      A1(1,3)=-SINTH
      A1(2,1)=0.
      A1(2,2)=COSPHI
      A1(2,3)=COSTH*SINPHI
      A1(3,1)=0.
      A1(3,2)=-SINPHI
      A1(3,3)=COSTH*COSPHI
      B1(1)=P
      B1(2)=Q
      B1(3)=R
      NEQ=3
      CALL COMB(A1,NEQ,4,B1,1,NER,DET)
      YP(10)=B1(1)
      YP(11)=B1(2)
      YP(12)=B1(3)
      IF(KP.EQ.4) KP=0
      RETURN
      END
VV
```

```
      SUBROUTINE DRAG(DY,DK,DN,P,R,V)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FU,G,NST,NVAL,
     *PI,RHO,SP,UU,WL,XLG,XFG,CDLL,CDNN
      COMMON/X/ ISECT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
      COMMON /Z/ AR,ARL,ARL2,ARL3,ARF,ARF2,ARF3,ARFL,ARFL2,ARF2L,B3B
      P2=P*P
      R2=R*R
      V2=V*V
      RP2=R*P*2.
      VP2=V*P*2.
      VR2=V*R*2.
      VO=V-FU*P/WL
      ONE=SIGN(1.0,VO)
      IF(R.EQ.0.)GO TO 7
      X0=-VO/R
 7    CONTINUE
      AREA=DI(NST)
      AREAL=DFI(NST)
      AREAL2=DF2I(NST)
      AREAL3=DF3I(NST)
      AREAF=DCI(NST)
      AREAF2=DC2I(NST)
      AREAF3=DC3I(NST)
      AREAFL=DCFI(NST)
      AFL2=DCF2I(NST)
      AF2L=DC2FI(NST)
      DY=-CDLL*(V2*AREA+R2*AREAL2+P2*AREAF2+VR2*AREAL-RP2*AREAFL-
     *VP2*AREAF)
      DN=-CDLL*(V2*AREAL+R2*AREAL3+P2*AF2L+VR2*AREAL2-RP2*AFL2-
     *VP2*AREAFL)
      DK=CDLL*(V2*AREAF+R2*AFL2+P2*AREAF3+VR2*AREAFL-RP2*AF2L-
     *VP2*AREAF2)
      DKV=-CDNN*B3BI(NST)*P*ABS(P)
      IF(R.EQ.0.)GO TO 2
      IF(X0+XLG) 2,2,1
 1    IF(X0-XFG) 3,2,2
 3    CALL GLOM(X0)
      AY=-CDLL*(V2*AR+R2*ARL2+P2*ARF2+VR2*ARL-RP2*ARFL-VP2*ARF)
      AN=-CDLL*(V2*ARL+R2*ARL3+P2*ARF2L+VR2*ARL2-RP2*ARFL2-VP2*ARFL)
      AK=CDLL*(V2*ARF+R2*ARFL2+P2*ARF3+VR2*ARFL-RP2*ARF2L-VP2*ARF2)
      ONEP=SIGN(1.0,-X0)
      DY=(DY-AY*2.)*ONEP
      DK=(DK-AK*2.)*ONEP
      DN=(DN-AN*2.)*ONEP
 2    DY=DY*ONE*2.
      DK=2.*DK*ONE +DKV
      DN=DN*ONE*2.
      RETURN
      END
```

```
      SUBROUTINE GEOM(X0)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FD,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN
      COMMON/X/ ISLCT(25),DI(25),DFI(25),DF2I(25),DF3I(25),DCI(25),
     *DC2I(25),DC3I(25),DCFI(25),DCF2I(25),DC2FI(25),B3BI(25),XSW(25)
      COMMON /Z/ AR,ARL,ARL2,ARL3,ARF,ARF2,ARF3,ARFL,ARFL2,ARF2L,B3B
      YO(X0,X1,X2,Y1,Y2)=Y1+(X0-X1)*(Y2-Y1)/(X2-X1)
      X0=X0+AA/WL
      DO 1 I=2,NST
      K=I
      IF(X0.GE.XSW(I-1).AND.X0.LT.XSW(I)) GO TO 2
    1 CONTINUE
    2 K1=K-1
      X1=XSW(K1)
      X2=XSW(K)
      AR=YO(X0 ,X1,X2,DI(K1) ,DI(K))
      ARL=YO(X0,X1,X2,DFI(K1),DFI(K))
      ARL2=YO(X0,X1,X2,DF2I(K1),DF2I(K))
      ARL3=YO(X0,X1,X2,DF3I(K1),DF3I(K))
      ARF=YO(X0,X1,X2,DCI(K1),DCI(K))
      ARF2=YO(X0,X1,X2,DC2I(K1),DC2I(K))
      ARF3=YO(X0,X1,X2,DC3I(K1),DC3I(K))
      ARFL=YO(X0,X1,X2,DCFI(K1),DCFI(K))
      ARFL2=YO(X0,X1,X2,DCF2I(K1),DCF2I(K))
      ARF2L=YO(X0,X1,X2,DC2FI(K1),DC2FI(K))
      B3B=YO(X0,X1,X2,B3BI(K1),B3BI(K))
      RETURN
      END
```

```
      SUBROUTINE AUXILY(PHI,U,XUDELU,DNPHIF,DKPHIF)
      COMMON /B/ P,Q,R,X,YY,Z,DUM1,V,W,DUM,THT,PSI
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,DUMMY,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,COLL,CDNN,FROUDE,CC,DD,ANU
      COMMON /U/ GI(25),SI(25),SI(25),PHO(25),TDRAF(25)
      COMMON /WALL/ VOLO,DRAGO,DELDRG
      YO(X0,X1,X2,Y1,Y2)=Y1+(X0-X1)*(Y2-Y1)/(X2-X1)
      CQ(DTRA)=2./(SP/SQRT(G*DTRA))**2
      NVAL=5
      IF(U.NE.1) GO TO 10
      KO=NVAL/2+1
      UO=1.
      RN=UO*SP*WL/ANU
      ARG=(ALOG10(RN)-2.)**2
      CFO=0.075/ARG+0.0004
      RN=U*SP*WL/ANU
      ARG=(ALOG10(RN)-2.)**2
      CF=0.075/ARG+.0004
      SWAO=GI(KO)
      SBAO=SI(KO)
      VOLO=SI(KO)
      TDRAFO=TDRAF(KO)*WL
      CBO=0.0
      IF(SBAO.LE.0.0) GO TO 9
      CFB=CFO*SWAO/SBAO
      CBO=0.029/SQRT(CFB)
      CFR=CQ(TDRAFO)
      IF(CFR.LT.CBO) CBO=CFR
    9 DRAGO=(CFO*SWAO+CBO*SBAO)*UO**2
   10 DO 1 I=2,NVAL
      K=I
      IF(PHI.GE.PHO(I).AND.PHI.LT.PHO(I-1)) GO TO 2
    1 CONTINUE
    2 SWAR=YO(PHI,PHO(K),PHO(K-1),GI(K),GI(K-1))
      SBAR=YO(PHI,PHO(K),PHO(K-1),SI(K),SI(K-1))
      VOLR=YO(PHI,PHO(K),PHO(K-1),SI(K),SI(K-1))
      TDRAFR=YO(PHI,PHO(K),PHO(K-1),TDRAF(K),TDRAF(K-1))*WL
      CBR=0.0
      IF(SBAR.LE.0.0) GO TO 11
      CFB=CF *SWAR/SBAR
      CBR=0.029/SQRT(CFB)
      CFR=CQ(TDRAFR)
      IF(CFR.LT.CBR) CBR=CFR
      PHIM=-PHI
   11 DO 3 I=2,NVAL
      K=I
      IF(PHIM.GE.PHO(I).AND.PHIM.LT.PHO(I-1)) GO TO 4
    3 CONTINUE
    4 SWAL=YO(PHIM,PHO(K),PHO(K-1),GI(K) ,GI(K-1))
      SBAL=YO(PHIM,PHO(K),PHO(K-1),SI(K),SI(K-1))
      VOLL=YO(PHIM,PHO(K),PHO(K-1),SI(K),SI(K-1))
      TDRAFL=YO(PHIM,PHO(K),PHO(K-1),TDRAF(K),TDRAF(K-1))*WL
      CBL=0.0
      IF(SBAL.LE.0.0) GO TO 12
      CFB=CF *SWAL/SBAL
      CBL=0.029/SQRT(CFB)
      CFR=CQ(TDRAFL)
      IF(CFR.LT.CBL) CBL=CFR
   12 CONTINUE
      U2=U*U
```

```
      DRAGR=(CF  *SWAR+CBR*SBAR)*U2
      DRAGL=(CF  *SWAL+CBL*SBAL)*U2
      DRAGV=DRAGR+DRAGL
      XUR=DRAGU-DRAGR
      XUL=DRAGU-DRAGL
      XUDELU=XUR+XUL
      DFLDRG=-XUDFLU
      BBN=BB/WL
      DNPHIF=-(XUR-XUL)*BBN
      DKPHIF=-(VOLR-VOLL) *BBN*2./FROUDE**2
      RETURN
      END
vv
```

```
      SUBROUTINE THRUST(U,THT,DFTH,TX,TY,TK,TN,SHIPDG,TOTLDG)
      DIMENSION DELJ(4),DP(4),TJET(4)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FU,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN
      COMMON /THRST/ TCON1,TCON2,TCON3,IDRAG,CCO,THTO
      COMMON /TVCC/ XARM,ZARM,BACE,YARM(4),DELJET(4),RMCP(4),NJET
     *,ALPHA(4)
      DELT(XX)=XX                                                         FT9
      DELH(YY)=0.01334*YY**2+0.2667*ABS(YY)                               FT9
      FMIP(SS)=16.6*(SS/1.689)**2-190.*(SS/1.689)+528000.                        C
      DGMOM(WW)=WW/1.689*(3900.-350.*(4.-TCON4))
      RMIP(SS)= 2.4*(SS/1.689)**2-10.*(SS/1.689)+82000.
      TCON3=0.                                                                   C
      TCON4=RMCP(1)+RMCP(2)+RMCP(3)+RMCP(4)
      IF(U.NL.1.) GO TO 1
      CALL RESOLD(SP,CCO,THTO,SHIPDG,TOTLDG)
      THMEAN=TOTLDG
      IF(CC.NE.CCO) CALL RESOLD(SP,CC,THT,DUMMY,DUMMY)
      V=SP
      THMIP=FMIP(V)
      COFF=.5*RHO*WL**2*SP**2
      CONST1=100000./COFF
      CONST2=60000./COFF
      THMIPO=THMIP/COFF
      THMARG=TCON3/COFF
      THCONT=THMIPO-THMARG
      THMCP=THCONT
      THREVS=RMIP(V)/COFF
      THTURN=THMEAN
      IF(SPTURN.EQ.SP) GO TO 3
      CALL RESOLD(SPTURN,CC,THT,DUMMY,THTURN)
      THMIPO=FMIP(SPTURN)/COFF
      THCONT=THMIPO-THMARG
    3 IF(THTURN.GT.THCONT) THTURN=THCONT
      DIFF=THCONT-THTURN
      THRQD=THMCP -DIFF
      DO 4 I=1,NJET
      DELJ(I)=DELT(DELJET(I))*DTR
      DP(I)=DELH(DELJET(I))
      IF(ABS(DELJET(I)).EQ.90.) DP(I)=0.
      IF(DELJET(I).EQ.180.) DP(I)=0.
    4 CONTINUE
      GO TO 5
    1 CONTINUE
      V=U*SP
      CALL RESOLD(V,CC,THT,SHIPDG,TOTLDG)
      THMIP=FMIP(V)
      THMIPO=THMIP/COFF
      THCONT=THMIPO-THMARG
      THRQD=THCONT-DIFF
      THREVS=RMIP(V)/COFF
    5 CONTINUE
      IF(DFTH.NE.0) GO TO 26
      DO 25 I=1,NJET
      ANJET=NJET
      TJET(I)=THCONT/ANJET
      TJET(I)=TJET(I)-(1.-RMCP(I))*CONST1
      IF(DELJET(I).EQ.180.) TJET(I)=THREVS-(1.-RMCP(I))*CONST2
      IF(ABS(DELJET(I)).EQ.90.) TJET(I)=THREVS-(1.-RMCP(I))*CONST2
```

```
      TJET(I)=TJET(I)*(1.-DP(I)/100.)
   25 CONTINUE
      GO TO 10
   26 CONTINUE
      PAIR=NJET/2.
      THIGH=(THRTPU-DGMOM(V)/COFF)/NJET
      RQD=THRQD/PAIR
      IF(THIGH.GE.RQD) THIGH=RQD
      TLOW=RQD-THIGH
      NJT=NJET-1
      DO 40 I=1,NJT,2
      TJET(I)=THIGH
   40 TJET(I+1)=TLOW
      IF(DFTH.GT.0) GO TO 10
      DO 50 I=1,NJT,2
      TJET(I)=TLOW
   50 TJET(I+1)=THIGH
   10 TX=0.
      TY=0.
      TK=0.0
      TN=0.
      DO 30 I=1,NJET
      TI=TJET(I)
      DELI=DELJ(I)
      ALFI=ALPHA(I)*DTR
      TX=TX+TI*COS(ALFI)*COS(DELI)
      TY=TY+TI*COS(ALFI)*SIN(DELI)
      TK=TK+TI*SIN(ALFI)*YARM(I)
      TN=TN-TI*COS(ALFI)*COS(DELI)*YARM(I)
   30 CONTINUE
      IF(DFTH.EQ.0.) TX=TX-DGMOM(V)/COFF
      TK=TK-TY*ZARM
      TN=TN-TY*XARM
      RETURN
      END
```

```
      SUBROUTINE RESOLD(V,DRFT,TRIM,SHIPDG,TOTLDG)
      COMMON /WALL/ VOLO,DRAGO,DELDRG
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UU,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
      COMMON /TEMP/SX,SY,SK,SN,WAVEDG,AERODG,HYDROF,SPRYDG,SEALDG,
     *SKINDG,FINDG
      COMMON /ABC/ DRAFT(25),WEIGHT,BUBB,BUBL,WALB,SLBOW,SLSTRN,THETA,
     *DEPTH,SPRAYL
      RO=RHO
      IF(V.NE.SP) GO TO 10
      BOL=BUBB/BUBL
      HOL=DRFT/BUBL
   10 C= VOLO*RO*G/WEIGHT*2.*WL**3
      F=V/SQRT(G*BUBL)
      CVT=WEIGHT/(RO*G)/BUBL**3
      CALL WAVE(BOL,HOL,C,F,WAVET)
      WAVEDG=0.5*RO*G*BUBL**3*CVT**2*WAVET
      CALL AERO(WL,DEPTH,BUBB,WALB,DRFT,V,AERODG)
      CALL SPRAY(V,SPRAYL,SPRYDG)
      CALL SEAL(BUBB,V,SLBOW,SLSTRN,THETA,SEALDG)
      PREO=0.5* RO*WL**2*SP**2
      SKINDG=2.*DRAGO*PREO
      FINDG=-SX*PREO
      SHIPDG=(WAVEDG+AERODG        +SPRYDG+SEALDG+SKINDG)/PREO
      TOTLDG=SHIPDG+DELDRG+FINDG/PREO
      RETURN
      END
```

```
      SUBROUTINE WAVE(BOL,HOL,C,F,TOTAL)
      PI=3.14159
      W=10.
      W1=2.*W
      TOTAL=0.
      WAVEDG=0.
      DIFF=1.
      DO 10 M=1,20
      EPSL=2.
      AM=M-1
      IF(AM.EQ.0.) EPSL=1.
      GAMA=1.-C
      BIOL=C/(4./3.*HOL)
      ALFA=4.*PI*AM*F**2/W
      BETA=2.*PI*BOL*AM/W1
      FAC=(1.+SQRT(1.+ALFA**2))/SQRT(1.+ALFA**2)
        SB=SQRT(0.5+.5*SQRT(1.+ALFA**2))
      AK1=0.5/F**2
      SIGMA=COS(AK1*SB)/SB-SIN(AK1*SB)/(AK1*SB**2)
      DELTA=AK1*SB**2*HOL*2.
      A=8.*BIOL/(AK1*SQRT( W /F**2))*COS(BETA)*(1.-EXP(-DELTA))*SIGMA
     *   /SB**2
      IF(AM) 5,6,5
    5 PSI=SIN(BETA)/(PI*AM/W1)
      GO TO 7
    6 PSI=2.*BOL
    7 B=2./BOL*SQRT(AK1/ W1)*GAMA*SIN(AK1*SB)*PSI
      WAVEDG=(A-B)**2*FAC*F**2*EPSL+WAVEDG
      IF(TOTAL.EQ.0.) GO TO 8
      DIFF=ABS((WAVEDG-TOTAL)/TOTAL)
    8 TOTAL=WAVEDG
      IF(DIFF.LE.0.001) GO TO 99
   10 CONTINUE
   99 RETURN
      END
```

```
SUBROUTINE AERO(SLFT,DEPTH,B,B1,DRFT,V,AERODG)
ANU=1.56E-04
RO=0.00238
RENOLD=V*SLFT/ANU
CF=0.455/ALOG10(RENOLD)**2.58
AREA=SLFT*(B+B1+(DEPTH-DRFT)*2.)
FRONT=(DEPTH-DRFT)*(B+B1*2.)
PRE=0.5*RO*V**2
FRNTDG=PRE*0.6*FRONT
SKINDG=PRE*CF*AREA
AERODG=FRNTDG+SKINDG
RETURN
END
```

```
      SUBROUTINE SPRAY(V,SPRAYL,SPRYDG)
      COMMON /ABC/ DRAFT(25),WEIGHT,BUBB,BUBL,WALB,SLBOW,SLSTRN,THETA,
     *DEPTH
      COMMON /CDE/ DRISE(23),ENTRCE(23),CHINE(23),HSPRAY(23)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DIR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,COLL,CONN,FROUDE,CC,DD,ANU
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      RO=RHO
      FAC=3.14159/180.
      DO 10 I=1,NST
   10 HSPRAY(I)=0.
      DO 30 I=1,NST
      ANG=SIN(DRISE(I)*FAC)*SIN(ENTRCE(I)*FAC)
      HSPRAY(I)=V**2/(2.*G)*ANG**2
      CHK=CHINE(I)-DRAFT(I)
      IF(CHK.LT.0.0) CHK=0.0
      IF(HSPRAY(I).GT.CHK) HSPRAY(I)=CHK
   30 CONTINUE
      CALL SIMPSO(N1,DEL1,HSPRAY(1),AREA1)
      CALL SIMPSO(N2,DEL2,HSPRAY(N1),AREA2)
      AREA=AREA1+AREA2
      M=N1+1
      U=V*COS(ENTRCE(M)*FAC/2.)
      RENOLD=V*SPRAYL/ANU
      CF=0.075/(ALOG10(RENOLD)-2.)**2 +0.0004
      PRE=0.5*RO*U**2
      SPRYDG=PRE*AREA*2.*CF
      RETURN
      END
```

```
      SUBROUTINE SEAL(B,V,SLBOW,SLSTRN,THETA,SEALDG)
      COMMON /ABC/ DRAFT(25)
      COMMON /IN/ AA,AIX,AIZ,AM,BH,CB,ZZ,DIR,DXDU,FD,G,NST,NVAL,
     *PI,RHO,SP,UU,WL,XLG,XFG,COLL,CONN,FROUDE,CC,DD,ANU
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      N3=N1+1
      RO=RHO
      PRE=0.5*RO*V**2
      ANG=THETA*3.14159/180.
      RBOW=0.
      SL1=DRAFT(N3)/SIN(ANG)
      IF(SL1.GE.SLBOW) SL1=SLBOW
      BOWSL=SL1*COS(ANG)
      IF(BOWSL.LE.0.) GO TO 10
      RENOLD=BOWSL     *V/ANU
      CF=0.044/(RENOLD**(1./6.))
      RBOW=PRE*B*BOWSL      *CF
   10 CONTINUE
      RSTRN=0.
      SL2=DRAFT(1 )/SIN(ANG)
      IF(SL2.GE.SLSTRN) SL2=SLSTRN
      STRNSL=SL2*COS(ANG)
      IF(STRNSL.LE.0.) GO TO 20
      RENOLD=STRNSL    *V/ANU
      CF=0.044/(RENOLD**(1./6.))
      RSTRN =PRE*B*STRNSL       *CF
   20 SEALDG=RBOW+RSTRN
      RETURN
      END
```

```
      SUBROUTINE LINVEL(FXLV,FYLV,FZLV,FKLV,FMLV,FNLV)
      COMMON /B/ P,Q,R,X,Y,Z,U,V,W,PHI,THT,PSI
      COMMON /NOD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      FXLV=0.
      FYLV=(DYV*V+DYW*W+DYP*P+DYQ*Q+DYR*R)*U
      FZLV=(DZV*V+DZW*W+DZP*P+DZQ*Q+DZR*R)*U
      FKLV=(DKV*V+DKW*W+DKP*P+DKQ*Q+DKR*R)*U
      FMLV=(DMV*V+DMW*W+DMP*P+DMQ*Q+DMR*R)*U
      FNLV=(DNV*V+DNW*W+DNP*P+DNQ*Q+DNR*R)*U
      RETURN
      END
```

```
      SUBROUTINE INERTIA(FXIC,FYIC,FZIC,FMIC,FNIC,FKIC)
      COMMON /B/ P,G,R,X,YY,Z,U,V,W,PHI,THT,PSI
      COMMON /NDD/ DYP,DYQ,DYR,DYV,DYW,DYDP,DYDQ,DYDR,DYDV,DYDW,
     *             DZP,DZQ,DZR,DZV,DZW,DZDP,DZDQ,DZDR,DZDV,DZDW,
     *             DKP,DKQ,DKR,DKV,DKW,DKDP,DKDQ,DKDR,DKDV,DKDW,
     *             DMP,DMQ,DMR,DMV,DMW,DMDP,DMDQ,DMDR,DMDV,DMDW,
     *             DNP,DNQ,DNR,DNV,DNW,DNDP,DNDQ,DNDR,DNDV,DNDW
      FXIC= -DYDV*R*V-DYDP*R*P-DYDR*R*R+DYDW*W*Q+DZDQ*Q*Q+DZDP*P*Q
      FYIC= -DZDW*W*P-DZDQ*P*Q-DZDP*P*P
      FZIC= DYDV*V*P+DYDR*P*R+DYDP*P*P
      FMIC= -DYDR*P*V+DYDP*R*V+(DKDP-DNDR)*P*R+DNDP*(R*R-P*P)
     * +DZDP*W*R+DMDP*Q*R
      FNIC=-DZDP*W*Q+DZDQ*W*P+(DMDQ-DKDP)*P*Q+DKDQ*(P*P-Q*Q)
     * -DYDP*V*Q-DNDP*Q*R
      FKIC=(DZDW-DYDV)*V*W-(DYDR+DMDW)*R*W+(DZDQ+DNDV)*V*Q
     *+(DNDR-DMDQ)*R*Q-DYDP*P*W+DZDP*V*P-DMDP*R*P+DNDP*Q*P
      RETURN
      END
```

```
      SUBROUTINE SEAWAV(WX,WY,WZ,WK,WM,WN,VOL,AO,Y,T)
      REAL MWK,MWM,MWN,MTM,MTN
      DIMENSION Y(12)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DIR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /SES/ HSW(25),DEL1,DEL2,N1,N2
      COMMON /TRAN/ FTX,MTM,MTN
      COMMON /WFOR/ FWX(25),FWY(25),FWZ(25),MWK(25),MWM(25),MWN(25),
     *AREA(25),FLEAK(25)
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      COMMON /BSLEAK/ BLEAK,SLEAK
      DO 1 I=1,NST
    1 CALL BUOY(I,Y,T)
C     INTEGRATE FOR WAVE FORCES AND MOMENTS
      Q1=Q2=Q3=Q4=Q5=Q6=0.
      NST1=NST-1
      NT=N1
      IF(N1.NE.NST1) GO TO 5
      NT=NST
      GO TO 6
    5 CALL SIMPSO(N2,DEL2,FWX(NT),Q1)
      CALL SIMPSO(N2,DEL2,FWY(NT),Q2)
      CALL SIMPSO(N2,DEL2,FWZ(NT),Q3)
      CALL SIMPSO(N2,DEL2,MWK(NT),Q4)
      CALL SIMPSO(N2,DEL2,MWM(NT),Q5)
      CALL SIMPSO(N2,DEL2,MWN(NT),Q6)
    6 CALL SIMPSO(NT,DEL1,FWX(1),R1)
      CALL SIMPSO(NT,DEL1,FWY(1),R2)
      CALL SIMPSO(NT,DEL1,FWZ(1),R3)
      CALL SIMPSO(NT,DEL1,MWK(1),R4)
      CALL SIMPSO(NT,DEL1,MWM(1),R5)
      CALL SIMPSO(NT,DEL1,MWN(1),R6)
      CALL SIMPSO(NT,DEL1,AREA(1),R7)
      CALL SIMPSO(NT,DEL1,FLEAK(1),R8)
      DEMEN=0.5*RHO*WL**2*SP**2
C     WX=(Q1+R1+FTX)/DEMEN
      WX=(Q1+R1     )/DEMEN
      WY=(Q2+R2)/DEMEN
      WZ=(Q3+R3)/DEMEN
      WK=(Q4+R4)/DEMEN/WL
C     WM=(Q5+R5+MTM)/DEMEN/WL
      WM=(Q5+R5     )/DEMEN/WL
C     WN=(Q6+R6+MTN)/DEMEN/WL
      WN=(Q6+R6     )/DEMEN/WL
      VOL=R7
      AO=R8
      BLEAK=FLEAK(N1)*0.5
      SLEAK=FLEAK(1)*0.5
      IF(INWGT.EQ.0) GO TO 2
      WX=WX-WXO
      WM=WM-WMO
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BUOY(I,Y,T)
C     DEFINITION OF PARAMETERS
      REAL MWSK,MWSM,MWSN,MWPK,MWPM,MWPN,MWK,MWM,MWN,MBK,MBM,MTM,MTN
      DIMENSION JTRAN(4),SGN(4),DINT(4),Y(12)
      DIMENSION AREAD(25),DFT(25,4),BEAM(25,4)
      COMMON /GEOMM/ NSW(25),W1(25,25),W2(25,25),D1(25,25)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,COLL,CONN,FROUDE,CC,DD,ANU,ALOD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /SES/ HSW(25)
      COMMON /THRST/ TCON1,TCON2,TCON3,IDRAG,CCO,THTO
      COMMON /TRAN/ FTX,MTM,MTN
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25)
      COMMON /WFOR/ FWX(25),FWY(25),FWZ(25),MWK(25),MWM(25),MWN(25),
     *AREA(25),FLEAK(25)
      COMMON /X/ DUMMY(300),XSW(25)
      COMMON /BEEM/ BEME(25),BEAMI(25),BEAMF1(25),BEAMF2I(25)
     *,BEAMF3I(25)
      COMMON /BEEM2/ BEM2(25),BEM3(25),ARMS,ARMP
      COMMON /BSEAL/ ZARMSL,AREASL
      DATA SGN/-1.,1.,-1.,1./
      IF(I.EQ.1.AND.IBUG.NE.0) WRITE(6,202) AA,BB,CC,DD,Y(1),Y(7),Y(9)
     *,Y(10),Y(11),Y(12)
  202 FORMAT(1H1, *AA,BB,CC,DD,U,SURGE,HEAVE,PHI,THT,PSI*/10G12.4)
      FWX(I)=FWY(I)=FWZ(I)=MWK(I)=MWM(I)=MWN(I)=0.
      AREA(I)=0.
      AREAD(I)=0.
      BEME(I)=0.
      BEM2(I)=BEM3(I)=0.
      JJ=NSW(I)
      IF(JJ.LQ.1) RETURN
      RHOG=RHO*G
      DO 1 K=2,3
      JTRAN(K)=0
      DFT(I,K)=BEAM(I,K)=0.
      DO 2 J=2,JJ
      D1TOP=D1(I,J)
      D1BOT=D1(I,J-1)
      W1TOP=W1(I,J)
      W1BOT=W1(I,J-1)
      W2TOP=W2(I,J)
      W2BOT=W2(I,J-1)
      CALL SEGAL(K,W1TOP,W1BOT,W2TOP,W2BOT,D1TOP,D1BOT,BETA,HYPOT)
      WT=BB
      IF(K.GT.2) WT=-WT
      Z=DD-HSW(I)-D1TOP
      HGT=CC-D1TOP-HSW(I)-F(I)*TAN(THTO)
      CALL SWAVE(F(I),WT,Z,Y,T,ETA)
      HCHK=HGT+ETA
      IF(HCHK.GE.0.) GO TO 2
      DFT(I,K)=D1TOP+HCHK
      BEAM(I,K)=W1TOP
      JTRAN(K)=J
      DINT(K)=DFT(I,K)-D1BOT
      IF(DINT(K).GT.0.)GO TO 1
      JTRAN(K)=1
      GO TO 1
    2 CONTINUE
      JTRAN(K)=JJ
      DFT(I,K)=D1TOP
```

```
      BEAM(I,K)=W1TOP
      DINT(K)=D1TOP-D1BOT
1     CONTINUE
      BEM2(I)=BEAM(I,2)
      BEM3(I)=BEAM(I,3)
      IF(DFT(I,2).LT.0.) DFT(I ,2)=0.
      IF(DFT(I,3).LT.0.) DFT(I ,3)=0.
      AREAD(I)=0.5*DFT(I,2)*(BEAM(I,2)+W1(I,1))+0.5*DFT(I,3)*(BEAM(I,3)+
     1      W1(I,1))
      ARMS=BB+0.25*(BEAM(I,2)+W1(I,1))
      ARMP=-(BB+0.25*(BEAM(I,3)+W1(I,1)))
      DINT(1)=DINT(2)
      DINT(4)=DINT(3)
      CALL VOLUME(I ,BB,JTRAN,DINT,DWET,FLK,AR,ASEAL,HSEAL)
      AREA(I)=AR
      FLEAK(I)=FLK
      RN=Y(1)*SP*WL/ANU
      ARG=(ALOG10(RN)-2.)**2
      CF=0.075/ARG+.0004
      DPO=CC-F(I)*TAN(THTO)
      FWX(I)=    -CF*(DFT(I,2)+DFT(I,3)-2.*DPO)*RHO*(SP*Y(1))**2
      FWY(I)=0.
      FWZ(I)=-AREAD(I)*RHOG
      MWK(I)=-RHOG*(ARMS*0.5*DFT(I,2)*(BEAM(I,2)+W1(I,1))+
     * ARMP*0.5*DFT(I,3)*(BEAM(I,3)+W1(I,1)))
      MWM(I)= AREAD(I)*F(I)*RHOG
      MWN(I)=0.
      RETURN
      END
```

```
      SUBROUTINE SWAVE(XC,YC,ZC,Y,T,ETA)
      DIMENSION Y(12)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CDNN,FROUDE,CC,DD,ANU,ALUD,CLD
     *,NC,NG,SPTURN,IPLOT,IPT,AIY
      COMMON /WAV/ DWET,WAMP,WPER,CEL,CAY,IBUG,F(25),BETA,IW,WDEP,OFFSET
     *,WLG,ICO,XO,RO,ETAO
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO

      SINH(U)=(EXP(U)-EXP(-U))/2.
      SECH(ARG)=2./(EXP(ARG)+EXP(-ARG))
      DATA C00,C01,C02,C03,C04/11.53924656,-52.76716255,107.1876292,
     *-100.9056818,35.23071874/
      HEAVL=Y(9)*WL
      PHI=Y(10)
      THT=Y(11)
      PSI=Y(12)
      PSO=BETA-PSI
      COST=COS(THT)
      TW=T*WL/SP
      UT=(Y(7)*COS(BETA)+Y(8)*SIN(BETA))*WL
      ARG1=XC*TAN(THT)-HEAVE/COST-YC*TAN(PHI)/COST
      ARG2=(XC*COST+ZC*SIN(THT))*COS(PSO)+YC*SIN(PSO)
      GO TO (1,2,3),IW
C
C     SINUSOIDAL WAVE
C
    1 ETA=-WAMP*SIN(CAY*XC)
      IF(INWGT.EQ.0) RETURN
      CT=CEL*T*WL/SP
      ETA=-WAMP*SIN(CAY*(ARG2+UT-CT))/COST-ARG1
      RETURN
C
C     SOLITARY WAVE
C
    2 OFFSET=0.50*CEL*WPER
      A1=CAY*(XC-OFFSET)
      ETA=WAMP*SECH(A1)**2
      IF(INWGT.EQ.0) RETURN
      CT=CEL*TW
      I=ABS(UT-CT)/WLG
      A1=CAY*(ARG2+UT-CT+OFFSET+I*WLG)
      ETA=WAMP*SECH(A1)**2/COST-ARG1
      RETURN
C
C     EXPLOSION WAVE
C
    3 ETA=0.
      IF(INWGT.EQ.0) RETURN
      H=WDEP
      TO=XO/SQRT(G*H)
      TO=80.
      TW=TW+TO
      R=UT+XO
      RF=R/TW/SQRT(G*H)
      IF(RF.GE..3) GO TO 4
      X=1./(4.*RF**2)
      GO TO 5
    4 RF2=RF*RF
      RF3=RF2*RF
```

```
      RF4=RF3*RF
      X =CO4*RF4+CO3*RF3+CO2*RF2+CO1*RF+COO
    5 CAY=X/H
      OMEGA=CAY*SQRT(G*TANH(X)/CAY)
      CEL=OMEGA/CAY
      CT=CEL*TW
      HK2=2.*X
      SHK2=SINH(HK2)
      ARG=HK2/SHK2
      ARG3=1.+ARG
      ARG4=-ARG3/(ARG*(1.-HK2/TANH(HK2))+0.5*ARG3**2-ARG3)
      ROK=CAY*RO
      CALL BESSEL(3,ROK,BJ3)
      ARG5=(CAY*(ARG2+UT-CT))/COST
      ETA=(ETAU*RO/R)*SQRT(ARG4)*BJ3*COS(ARG5)-ARG1
      RETURN
      END
```

```
      SUBROUTINE VOLUME(I,BB,JTRAN,DINT,DWET,FLEAK,AREA)
C     SUBROUTINE TO CALCULATE AREA BETWEEN CALM WATER SURFACE
C     AND WET DECK AND LEAKAGE FOR CROSS SETION I
      DIMENSION JTRAN(4),DINT(4)
      COMMON /GEOMM/ NSW(25),W1(25,25),W2(25,25),D1(25,25)
      FLEAK=0.
C     STARBOARD SIDEWALL
      DS=DINT(2)
      JS=JTRAN(2)
      IF(JS.EQ.1) GO TO 1
      JS1=JS-1
      HGTS=DWET-D1(I,JS1)-DS
      GO TO 2
    1 HGTS=DWET-DS                                                    C
      FLEAK=-DS
C     PORT SIDEWALL
    2 DP=DINT(3)
      JP=JTRAN(3)
      IF(JP.EQ.1) GO TO 3
      JP1=JP-1
      HGTP=DWET-D1(I,JP1)-DP
      GO TO 4
    3 HGTP=DWET-DP                                                    C
      FLEAK=FLEAK-DP
    4 AREA=BB*(HGTP+HGTS)
      RETURN
      END
VV
```

```
      SUBROUTINE SEGAL(K,W1TOP,W1BOT,W2TOP,W2BOT,DTOP,DBOT,BETA,HYPOT)
C     SUBROUTINE TO CALCULATE SEGMENT LENGTH AND ANGLE.
      DDIF=DTOP-DBOT
      WDIF=W1TOP-W1BOT
      IF(K.EQ.2.OR.K.EQ.3) WDIF=W2TOP-W2BOT
      BETA=ATAN2(WDIF,DDIF)
      HYPOT=SQRT(WDIF**2+DDIF**2)
      RETURN
      END
```

```
      SUBROUTINE DRAGV(DZ,DM,DK,F,W,Q,K)
      COMMON /BEEM/ BEAM(25),BEAMI(25),BEAMFI(25),BEAMF2I(25)
     *,BEAMF3I(25)
      COMMON /BEEM2/ BEM2(25),BEM3(25),ARMS,ARMP
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DIR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,COLL,CONN
      COMMON /X/ DUMMY(300),XSW(25)
      COMMON /Z1/ BR,BRL,BRL2,BRL3
      DIMENSION F(25)
      TRAP(H,Y1,Y2)=0.5*H*(Y1+Y2)
      DO 3 I=1,NST
      BEAM(I)=BEM2(I)
      IF(K.EQ.3) BEAM(I)=BEM3(I)
    3 CONTINUE
      W2=W*W
      Q2=Q*Q
      WQ2=W*Q*2.
      ONE=SIGN(1.0,W)
      IF(Q.EQ.0.) GO TO 17
      X0=W/Q
   17 CONTINUE
      BEAMI(1)=BEAMFI(1)=BEAMF2I(1)=BEAMF3I(1)=0.
      DO 14 I=2,NST
      H=XSW(I)-XSW(I-1)
      H=H*WL
      BFI=BEAM(I)*F(I)
      BFI1=BEAM(I-1)*F(I-1)
      BF2I=BFI*F(I)
      BF2I1=BFI1*F(I-1)
      BF3I=BF2I*F(I)
      BF3I1=BF2I1*F(I-1)
      B1=TRAP(H,BEAM(I),BEAM(I-1))
      B2=TRAP(H,BFI,BFI1)
      B3=TRAP(H,BF2I,BF2I1)
      B4=TRAP(H,BF3I,BF3I1)
      BEAMI(I)=BEAMI(I-1)+B1/WL**2
      BEAMFI(I)=BEAMFI(I-1)+B2/WL**3
      BEAMF2I(I)=BEAMF2I(I-1)+B3/WL**4
      BEAMF3I(I)=BEAMF3I(I-1)+B4/WL**5
   14 CONTINUE
      AREA=BEAMI(NST)
      AREAL=BEAMFI(NST)
      AREAL2=BEAMF2I(NST)
      AREAL3=BEAMF3I(NST)
      DZ=-CONN*(W2*AREA+Q2*AREAL2-WQ2*AREAL)
      DM= CONN*(W2*AREAL+Q2*AREAL3-WQ2*AREAL2)
      IF(Q.EQ.0.) GO TO 12
      IF(X0+XLG) 12,12,11
   11 IF(X0-XFG) 13,12,12
   13 CALL GEOMV(X0)
      BZ=-CONN*(W2*BR+Q2*BRL2-WQ2*BRL)
      BM=-CONN*(W2*BRL+Q2*BRL3-WQ2*BRL2)
      ONEP=SIGN(1.,-X0)
      DZ=(DZ-BZ*2.)*ONEP
      DM=(DM-BM*2)*ONEP
   12 DZ=DZ*ONE
      DM=DM*ONE
      ARM=ARMS
      IF(K.EQ.3) ARM=ARMP
      DK= DZ*ARM
```

```
      RETURN
      END
```

```
      SUBROUTINE GEOMV(XOB)
C
C     VERTICAL DRAG
C
      COMMON /BEEM/ BEAM(25),BEAMI(25),BEAMFI(25),BEAMF2I(25)
     *,BEAMF3I(25)
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DIR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UU,WL,XLG,XFG,CDLL,CDNN
      COMMON /X/ DUMMY(300),XSW(25)
      COMMON /Z1/ BR,BRL,BRL2,BRL3
      YO(X0,X1,X2,Y1,Y2)=Y1+(X0-X1)*(Y2-Y1)/(X2-X1)
      XOB=XOB+AA/WL
      DO 1 I=2,NST
      K=I
      IF(XOB.GE.XSW(I-1).AND.XOB.LT.XSW(I)) GO TO  2
    1 CONTINUE
    2 K1=K-1
      X1=XSW(K1)
      X2=XSW(K)
      BR=YO(XOB,X1,X2,BEAMI(K1),BEAMI(K))
      BRL=YO(XOB,X1,X2,BEAMFI(K1),BEAMFI(K))
      BRL2=YO(XOB,X1,X2,BEAMF2I(K1),BEAMF2I(K))
      BRL3=YO(XOB,X1,X2,BEAMF3I(K1),BEAMF3I(K))
      RETURN
      END
vv
```

```
      SUBROUTINE PRESS(T,Y,VOL    ,AO,XC,YC,ZC,KC,MC,NC)
      REAL KC ,MC,NC
      DIMENSION Y(12)
      COMMON/ABC/ DRAFT(25),WEIGHT
      COMMON /IN/ AA,AIX,AIZ,AM,BB,CB,CF,DTR,DXDU,FO,G,NST,NVAL,
     *PI,RHO,SP,UO,WL,XLG,XFG,CDLL,CONN,FROUDE,CC,DD,ANU,ALOD,CLD
      COMMON /PRES/ CDIS,RHOWA,PHIO,PHI1,ATM,PMAX,AC,DEM,IPR
      COMMON /WGT/ BUOYAN,INWGT,WMO,WXO
      COMMON /FLOW/ PC,QF,QO,VDOTP,AOP,AI
      COMMON /BSLEAK/ BLEAK,SLEAK
      HEV=Y(9)
      PHI=Y(10)
      THT=Y(11)
      AF=49.
      IF(T.NE.0.) GO TO 1
      FB=BUOYAN*DEM
      PC=(WEIGHT-FB)/AC +ATM
      PCGAGE=PC-ATM
      AI=(PHIO+PHI1*PCGAGE)/(CDIS*SQRT(2.*(PCGAGE)/RHOWA))
      PMAX=ATM-PHIO/PHI1
      GO TO 10
    1 ASB=2.*BB*(BLEAK+SLEAK)
      AT=AI+AO+ASB
      GAM=1.4
      PDIF=POLD-ATM
      IF(PDIF.GT.0.) GO TO 20
      QF=PHIO
      QL=AI*CDIS*SQRT(2.*ABS(PDIF)/RHOWA)
      QO=AO*CDIS*SQRT(2.*ABS(PDIF)/RHOWA)
      IF(IPR.NE.0) WRITE(6,202) T,POLD
  202 FORMAT(1X,*PC LESS THAN ATMOSPHERIC PRESSURE*,
     *5X,*T=*,F10.2,5X,*PC=*,F10.2)
      GO TO 2
   20 IF(POLD.LT.PMAX) GO TO 3
      QF=-CDIS*AF*SQRT(ABS(POLD-PMAX)/RHOWA)
      QL=-AT*CDIS*SQRT(2.*PDIF/RHOWA)
      QO=-AO*CDIS*SQRT(2.*PDIF/RHOWA)
      IF(IPR.NE.0) WRITE(6,203) T,POLD
  203 FORMAT(1X,*PC GREATER THAN PMAX*,5X,*T=*,F10.2,5X,*PC=*,F10.2)
      GO TO 2
    3 QF  =PHIO+PHI1*(POLD-ATM)
      QL  =-AT*CDIS*SQRT(2.*(POLD-ATM)/RHOWA)
      QO  =-AO*CDIS*SQRT(2.*(POLD-ATM)/RHOWA)
    2 VOLDOT=QF+QL
      V=VOLD+VOLDOT*(T-TOLD)*WL/SP
      PC=POLD*V**GAM/VOL**GAM
      IF(PC.LT.ATM) PC=ATM
   10 PDIF=PC-ATM
      ZARM=DD-CC-HEV*WL
      AN =AC*THT                                                         C
      BTAN=WL*TAN(THT)                                                   C
      BTBL=BTAN-BLEAK
      IF(THT.LT.0.) BTBL=BTAN+SLEAK
      IF(BTBL.GE.18.) BTBL=18.
      IF(BTBL.LT.-18.) BTBL=-18.
      IF(BLEAK.GT.0.) ZARM=DD-0.5*BTBL
      IF(SLEAK.GT.0.) ZARM=DD+0.5*BTBL
      IF((BLEAK+SLEAK).NE.0.) AN=2.*BB*BTBL
      XC=     AN*PDIF/DEM                                                C
      YC=-PHI*AC*PDIF/DEM
```

```
      ZC=-AC*PDIF/DEM
      KC=-YC*ZARM/WL
      MC=XC*ZARM/WL                                                          C
      NC=0.
      POLD=PC
      TOLD=T
      VOLD=VOL
      IF(T.EQ.0.) RETURN
      VDOTP=VOLDOT
      AOP=VOL
      RETURN
      END
vv
```

```
      SUBROUTINE PLOTT(A1,A2,A3,A4,A5,A6,NP,NC,NG)
      REAL NUM(10)
      COMMON /PRNT/ DT,NSTEP,NPRNT,IP
      DIMENSION A1(500),A2(500),A3(500),A4(500),A5(500),A6(500)
      DIMENSION IZERO(6),RANGE(6),A(132),STAR(6),RSET(6),RANGM(6)
      DATA IZERO/21,66,111,21,66,111/
      DATA RSET/.1,.2,1.,2.,4.,10./
      DATA STAR/1H*,1H*,1H*,1HO,1HO,1HO/
      DATA BLANK/1H /
      DATA DASH /1H-/
      DATA EYE /1HI/
      DATA PLUS /1H+/
      DATA TEE/1HT/
      DATA NUM/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
      SF(Q)=IZ+Q*SCL
C
C     INITIALIZE
C
      NG=6
      NSET=6
      NCT=131
      NX=10
      KX=10
C
C     SCALING FOR AXIS
C
      DO 20 I=1,NG
      GO TO (21,22,23,24,25,27),I
   21 CALL MAXX(NP,A1,YMAX)
      GO TO 26
   22 CALL MAXX(NP,A2,YMAX)
      GO TO 26
   23 CALL MAXX(NP,A3,YMAX)
      GO TO 26
   24 CALL MAXX(NP,A4,YMAX)
      GO TO 26
   25 CALL MAXX(NP,A5,YMAX)
      GO TO 26
   27 CALL MAXX(NP,A6,YMAX)
   26 CALL SCALE(NSET,RSET,YMAX,RNG)
      RANGE(I)=RNG
   20 RANGM(I)=-RANGE(I)
C
C     PRINT Y-AXIS
C
      WRITE(6,200) RANGM(1),RANGE(1),RANGM(2),RANGE(2),RANGM(3),RANGE(3)
  200 FORMAT(1H1,F5.1,12X,7HHEAVE=*,13X,F4.1,4X,F5.1,11X,7HPITCH=*,
     *14X,F4.1,4X,F5.1,10X,11HWAVE HGT.=*,11X,F4.1)
      WRITE(6,201) RANGM(4),RANGE(4),RANGM(5),RANGE(5),RANGM(6),RANGE(6)
  201 FORMAT(1X,F5.1,13X,6HROLL=0,13X,,F4.1,4X,F5.1,13X,5HYAW=0,14X,
     *F4.1,4X,F5.1,10X,11HPRESS/100=0,11X,F4.1)
C
C     PREPARE PLOTTING ARRAY
C
      DO 1 I=1,NP
      DO 2 K=1,NCT
    2 A(K)=BLANK
      DO 3 J=1,NG
      IZ=IZERO(J)
      RNG=RANGE(J)
```

```
      SCL=NC/RNG
      IF(I.NE.1) GO TO 5
      IHI=IZ+NC
      ILO=IZ-NC
      KNT=10
      DO 6 K=ILO,IHI
      A(K)=PLUS
      IF(KNT.NE.NX) GO TO 6
      A(K)=EYE
      KNT=0
    6 KNT=KNT+1
    5 GO TO (7,8,9,10,11,14),J
    7 A(IZ)=PLUS
      IC=SF(A1(I))
      GO TO 12
    8 A(IZ)=PLUS
      IC=SF(A2(I))
      GO TO 12
    9 A(IZ)=PLUS
      IC=SF(A3(I))
      GO TO 12
   10 IC=SF(A4(I))
      GO TO 12
   11 IC=SF(A5(I))
      GO TO 12
   14 IC=SF(A6(I))
   12 A(IC)=STAR(J)
    3 CONTINUE
      IF(KX.NE.NX) GO TO 13
      IZ1=IZERO(1)
      IZ2=IZERO(2)
      IZ3=IZERO(3)
      A(IZ1)=DASH
      A(IZ2)=DASH
      A(IZ3)=DASH
      IF(I.EQ.1) GO TO 16
      K1=(I-1)/10+.1
      K2=K1+1
      IF(K1.GE.10) GO TO 17
      A(IZ1+1)=NUM(K2)
      A(IZ2+1)=NUM(K2)
      A(IZ3-1)=NUM(K2)
      GO TO 16
   17 I2=MOD(K1,10)
      I1=(K1-I2)/10+1
      I2=I2+1
      A(IZ1+1)=NUM(I1)
      A(IZ1+2)=NUM(I2)
      A(IZ2+1)=NUM(I1)
      A(IZ2+2)=NUM(I2)
      A(IZ3-2)=NUM(I1)
      A(IZ3-1)=NUM(I2)
   16 KX=0
   13 KX=KX+1
      WRITE(6,202) (A(K),K=1,NCT)
  202 FORMAT(1X,131A1)
    1 CONTINUE
      DO 15 I=1,NCT
   15 A(I)=BLANK
      IZ1=IZERO(1)
```

```
IZ2=IZERO(2)
IZ3=IZERO(3)
A(IZ1)=TEE
A(IZ2)=TEE
A(IZ3)=TEE
WRITE(6,202) (A(K),K=1,NCT)                                        C
RETURN
END
```

```
      SUBROUTINE MAXX(NP,A,YMAX)
      DIMENSION A(1)
      YMAX=A(1)
      DO 1 I=2,NP
    1 YMAX=AMAX1(YMAX,ABS(A(I)))
      RETURN
      END
```

```
      SUBROUTINE SCALE(NP,A,YMAX,RNG)
      DIMENSION A(1)
      DO 1 I=1,NP
      ISAVE=I
      IF(YMAX.LE.A(I)) GO TO 2
    1 CONTINUE
      IUP=YMAX
      RNG=IUP
      RETURN
    2 RNG=A(ISAVE)
      RETURN
      END
```

```
      SUBROUTINE PLOTXY(XP,YYP,NP)                                      C
      DIMENSION A(91),RANGE(4),AX(10)
      DIMENSION XP(500),YYP(500),IP(500)
      COMMON IP
      DATA BLANK /1H /
      DATA EYE/1HI/
      DATA DASH  /1H-/
      DATA PLUS /1H+/
      DATA STAR/1H*/
      DATA RANGE   /4.,5.,10./
      DATA AX/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
C
C     SCALE
C
      NR=3
      NR1=NR-1
      KXAXIS=0
      YMAX=ABS(YYP(1))
      DO 11 I=2,NP
      NPSAV=I
      IF(XP(I).LT.0.0.OR.ABS(YYP(I)).GT.80.) GO TO 18
   11 YMAX=AMAX1(YMAX,ABS(YYP(I)))
   18 NP=NPSAV
      YHI=80.
      YLO=-YHI
C
C     ORDER X
C
      DO 1 I=1,NP
      KNT=1
      DO 2 J=1,NP
      IF(I.EQ.J) GO TO 2
      IF(XP(I).GT.XP(J)) KNT=KNT+1
    2 CONTINUE
      IP(I)=KNT
    1 CONTINUE
C
C     INITIALIZE
C
      IZ=81
      IF(YYP(NP).LT.0.0) IZ=11
      KSAVL=0
      LINE=1
      NC=80
      NL=91
      SCL=NC/YHI
      NY=SCL
      LY=10
      KY=LY
      NX=(NY*5./10.)*2.
      LX=10
      KX=LX
      IF(YYP(NP).GE.0.0) WRITE(6,201)
  201 FORMAT(1H1,56X,7HY VS. X/
     *20X,3H+80,17X,3H+60,17X,3H+40,17X,3H+20,19X,1H0/)
      IF(YYP(NP).LT.0.0) WRITE(6,202)
  202 FORMAT(1H1,56X,7HY VS. X/
     *30X,1H0,18X,3H-20,17X,3H-40,17X,3H-60,17X,3H-80/)
C
C     PREPARE PLOTTING ARRAY
```

```
C
      DO 3 K=1,NL
      A(K)=PLUS
      IF(KY.NE.LY) GO TO 14
      A(K)=EYE
      KY=0
   14 KY=KY+1
    3 CONTINUE
      DO 9 I=1,NP
      A(IZ)=PLUS
      DO 4 J=1,NP
    4 IF(IP(J).EQ.I) IO=J
      IY=IZ-SCL*YYP(IO)
      IX=1+(XP(IO)*SCL*5./10.)*2.
      IF(KSAVE.EQ.0) GO TO 5
      IF(IX.NE.KSAVE) GO TO 7
    5 IF(IX.GT.LINE) GO TO 7
      A(IY)=STAR
      KSAVE=LINE
      IF(I.EQ.NP) GO TO 7
      GO TO 9
    7 IF(KX.NE.LX) GO TO 10
      KXAXIS=KXAXIS+1
      IF(KXAXIS.EQ.1) GO TO 17
      IF(YYP(NP).LT.0.0) GO TO 15
      IZONE=IZ+1
      IZTWO=IZ+2
      GO TO 16
   15 IZONE=IZ-2
      IZTWO=IZ-1
   16 A(IZONE)=AX(KXAXIS)
      A(IZTWO)=AX(1)
   17 A(IZ)=DASH
      KX=0
   10 KX=KX+1
      IF(A(IZ).NE.DASH.AND.A(IZ).NE.STAR) A(IZ)=PLUS
      WRITE(6,200) (A(IJ),IJ=1,NL)
  200 FORMAT(20X,91A1)
      IF(I.EQ.NP.AND.LINE.EQ.IX) CALL EXIT
      DO 8 K=1,NL
    8 A(K)=BLANK
      LINE=LINE+1
      GO TO 5
    9 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE  RUNGS (X,H,N,Y,YPRIME,INDEX)
      DIMENSION Y(12),YPRIME(12),Z(12),W1(12),W2(12),W3(12),W4(12)
CRUNGS - RUNGE-KUTTA SOLUTION OF SET OF FIRST ORDER O.D.E.  FORTRAN 99
C     DIMENSIONS MUST BE SET FOR EACH PROGRAM
C     X   INDEPENDENT VARIABLE
C     H   INCREMENT DELTA X, MAY BE CHANGED IN VALUE
C     N   NUMBER OF EQUATIONS
C     Y   DEPENDENT VARIABLE BLOCK       ONE DIMENSIONAL ARRAY
C     YPRIME  DERIVATIVE BLOCK  ONE DIMENSIONAL ARRAY
C     THE PROGRAMMER MUST SUPPLY INITIAL VALUES OF  Y(1) TO Y(N)
C     INDEX  IS A VARIABLE WHICH SHOULD BE SET TO ZERO BEFORE EACH
C     INITIAL ENTRY TO THE SUBROUTINE, I.E., TO SOLVE A DIFFERENT
C     SET OF EQUATIONS OR TO START WITH NEW INITIAL CONDITIONS.
C     THE PROGRAMMER MUST WRITE A SUBROUTINE CALLED DERIVE WHICH COM-
C     PUTES THE DERIVATIVES AND STORES THEM
C     THE ARGUMENT LIST IS   SUBROUTINE DERIVE(X,N,Y,YPRIME)
      IF (INDEX) 5,5,1
    1 DO 2 I=1,N
      W1(I)=H*YPRIME(I)
    2 Z(I)=Y(I)+(W1(I)*.5)
      A=X+H/2.
      CALL DERIVE(A,N,Z,YPRIME)
      DO 3 I=1,N
      W2(I)=H*YPRIME(I)
    3 Z(I)=Y(I)+.5*W2(I)
      A=X+H/2.
      CALL DERIVE(A,N,Z,YPRIME)
      DO 4 I=1,N
      W3(I)=H*YPRIME(I)
    4 Z(I)=Y(I)+W3(I)
      A=X+H
      CALL DERIVE (A,N,Z,YPRIME)
      DO 7 I=1,N
      W4(I)=H*YPRIME(I)
    7 Y(I)=Y(I)+(((2.*(W2(I)+W3(I)))+W1(I)+W4(I))/6.)
      X=X+H
      CALL DERIVE (X,N,Y,YPRIME)
      GO TO 6
    5 CALL DERIVE (X,N,Y,YPRIME)
      INDEX=1
    6 RETURN
      END
VV
```

```
      SUBROUTINE COMB(A,N,ND,B,M,NERR,D)
C     SOLUTION OF SIMULT.EQ. FORMING KUTTA COND.
       DIMENSION  A(1), B(1)
      EQUIVALENCE  (I,FI), (K,FK)
      D=NERR=1
   10 DO 90  I=1,N                                                      MISS0060
      AIJMAX = A(I)                                                     MISS0070
      IJMAX = I                                                         MISS0080
      IF(N.EQ.1)GO TO 30
      DO 25  J=2,N                                                      MISS0090
      IJ = I + (J-1)*ND                                                 MISS0100
      IF(ABS(A(IJ))-ABS(AIJMAX))25,25,20
   20 AIJMAX = A(IJ)                                                    MISS0120
      IJMAX = IJ                                                        MISS0130
   25 CONTINUE                                                          MISS0140
      IF  (AIJMAX)  30,999,30                                           MISS0150
   30 DO 35  J=1,N                                                      MISS0160
      IJ = I + (J-1)*ND                                                 MISS0170
   35 A(IJ) = A(IJ)/AIJMAX                                              MISS01 0
      D = D * AIJMAX                                                    MISS0190
      DO 40  J=1,M                                                      MISS0200
      IJ = I + (J-1)*ND                                                 MISS0210
   40 B(IJ) = B(IJ)/AIJMAX                                              MISS0220
      DO 70  K=1,N                                                      MISS0230
      IF  (K-I)  50,70,50                                               MISS0240
   50 KJMAX = IJMAX + (K-I)                                             MISS0250
      ARAT  =  -A(KJMAX)                                                MISS0260
      KJ = K                                                            MISS0270
      IJ = I                                                            MISS02 0
      DO 60    J=1,N                                                    MISS0290
      IF  (A(IJ))  55,58,55                                             MISS0300
   55 A(KJ) = ARAT*A(IJ) + A(KJ)                                        MISS0310
   58 KJ = KJ + ND                                                      MISS0320
   60 IJ = IJ + ND                                                      MISS0330
      A(KJMAX) = 0.0                                                    MISS0340
      KJ = K                                                            MISS0350
      IJ = I                                                            MISS0360
      DO 69 J=1,M                                                       MISS0370
      IF (B(IJ))  65,68,65                                              MISS03 0
   65 B(KJ) = ARAT*B(IJ) + B(KJ)                                        MISS0390
   68 KJ = KJ + ND                                                      MISS0400
   69 IJ = IJ + ND                                                      MISS0410
   70  CONTINUE                                                         MISS0420
      KJ = IJMAX - I+1                                                  MISS0430
   90 A(KJ) = FI                                                        MISS0440
      DO 100  I=1,N                                                     MISS0450
      K = I                                                             MISS0460
   93 I1 = K*ND - ND + 1                                                MISS0470
      FK = A(I1)                                                        MISS04 0
      IF (K-I)  93,100,95                                               MISS0490
   95 IJ = I                                                            MISS0500
      IK = K                                                            MISS0510
      DO 99  J=1,M                                                      MISS0520
      A(2) = B(IJ)                                                      MISS0530
      B(IJ) = B(IK)                                                     MISS0540
      B(IK) = A(2)                                                      MISS0550
      IJ = IJ + ND                                                      MISS0560
   99 IK = IK + ND                                                      MISS0570
  100 CONTINUE                                                          MISS05 0
      NERR  =    0                                                      MISS0590
```

```
  999 RETURN                                                        MISS0600
      END
```

```
      SUBROUTINE SIMPSO  (N,H,Y,A)
C     ROUTINE TO PERFORM SIMPSON INTEGRATION FOR EVEN NUMBER OF INCREMENTS.
C
C     N=NUMBER OF INDEPENDENT VARIABLES
C     H=INCREMENT
C     Y=INDEPENDENT VARIABLE
C     A=INTEGRAL
C
      DIMENSION Y(1)
      NN=N
      IF(MOD(NN,2).NE.1)    GO TO 10
   15 KOUNT=0
      N1=N-1
      A=Y(1)+Y(N)
      THIRDH=H/3.
      DO 1 I=2,N1
      IF(KOUNT.EQ.1) GO TO 2
      A=A+4.*Y(I)
      KOUNT=1
      GO TO 1
    2 A=A+2.*Y(I)
      KOUNT=0
    1 CONTINUE
      A=THIRDH*A
      RETURN
   10 A=0.0
      DO 20 I=1,N
      A=A+Y(I)
   20 CONTINUE
      A=A-0.5*Y(1)-0.5*Y(N)
      A=A*H
      RETURN
      END
vv
```

```
      SUBROUTINE BESSFL(IO,X,V)
      DIMENSION T(1000)
      TW=1./12.
      TH=1./3.
      OR=IO
      M=3.+3.*X**TW+9.*X**TH+AMAX1(OR,X)
      IF(MOD(M,2).NE.0) M=M+1
      M1=M-1
      M2=M-2
      T(M)=0
      T(M1)=1.
       Z=2./X
       J=M2+1
       MX=M2/2
       SNORM=0.
      DO 1 I=1,MX
       J=J-1
       T(J)=J*Z*T(J+1)-T(J+2)
       J=J-1
       T(J)=J*Z*T(J+1)-T(J+2)
 1      SNORM=SNORM+T(J)
       SNORM=2.*SNORM-T(1)
      V=T(IO+1)/SNORM
      RETURN
      END
```

DISTRIBUTION LIST

	Copies
Scientific Officer Director, Field Projects Earth Sciences Division Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217 Reference: Contract N00014-76-C-0261 Attention: Mr. Jacob L. Warner, Code 464	1
Administrative Contracting Officer DCAS-MA 3452 East Foothill Boulevard Pasadena, California 91107 Attn: Mr. James Chapman	1
Director, Naval Research Laboratory, Attn: Code 2627 Washington, D.C. 20375	6
Office of Naval Research Department of the Navy Arlington, Virginia 22217 Attn: Code 102IP	6
Defense Documentation Center Building 5, Cameron Station Alexandria, Virginia 22314	12
Office of Naval Research Branch Office, Pasadena 1030 East Green Street Pasadena, California 91106	1
John Hopkins Applied Physics Lab Attn: J. George	1
Naval Sea Systems Command Surface Effect Ship Project (PMS 304) P. O. Box 34401 Bethesda, Maryland 20034	
Attn: PMS 304-Z	1
PMS 304-Z1	1
PMS 304-40	1
David Taylor Naval Ship Research and Development Center Attn: Code 1630	1
Office of Naval Research Code 438 Attn: Robert Mindak	1

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Tetra Tech, Inc. 630 N. Rosemead Blvd. Pasadena, California 91107	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
Vulnerability of Surface Effect Vehicles to explosion-generated water waves

6

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
9 Interim Report

5. AUTHOR(S) (First name, middle initial, last name)
10 Richard B. Wade, T. W. Wier
Shen Wang

6. REPORT DATE 11 November 1976	7a. TOTAL NO. OF PAGES 152	7b. NO. OF REFS 14
8a. CONTRACT OR GRANT NO. N00014-76-C-0261 NEW b. PROJECT NO. 15 c. 12 155 p. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 14 TETRAT - TC-645 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of Navy Office of Naval Research

13. ABSTRACT

The objective of the study is to investigate the response of a typical surface effect vehicle (SEV) to an explosion wave environment. The present report deals with the first phase of the investigation, which covers the following two basic tasks: (a) analytical description and modeling of explosion-generated water waves, and (b) analytical treatment of SEV dynamics and motions when subjected to a disturbing function as defined in (a) above. The generation of surface waves due to an explosion is modeled mathematically as a function of the explosive yield, detonation depth and water depth. Further, the dynamic property of the propagated waves is treated to vary with the local water depth. The dynamics of SEV are modeled mathematically by considering the vehicle a rigid body having six degrees of freedom in space, subject to an appropriate constraint derived from the cushion air dynamics as well as to the environmental excitations due to waves. Non-linear contributions including effects due to large motions, viscous flows, and control logics are considered and the ship responses are solved numerically through time domain integrations. Sample examples have been exercised using this analytic model to examine the effects of several chosen environments on an SEV and the results are presented herein.

DD FORM 1 NOV 65 1473

403 146

UNCLASSIFIED
Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
SEV						
SES						
Waves						
Solitary waves						
Explosion-generated water waves						
Motions						
Hydrodynamics						
Seakeeping						
Maneuvering						

Security Classification